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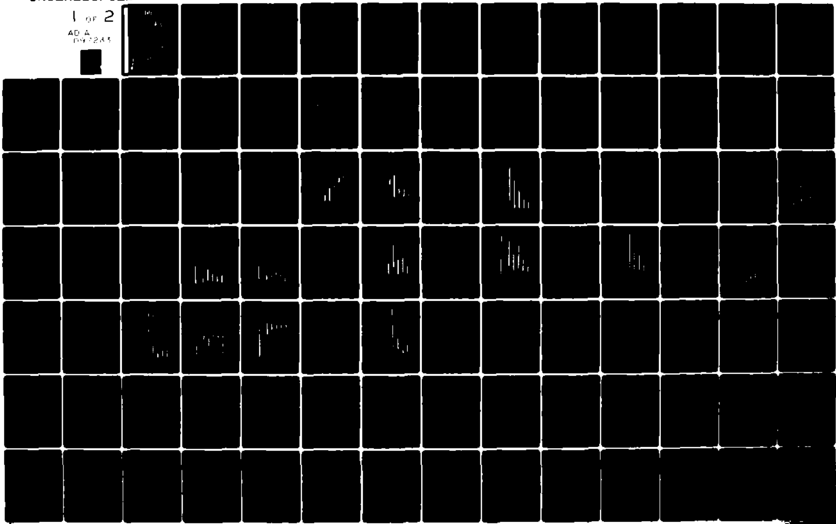

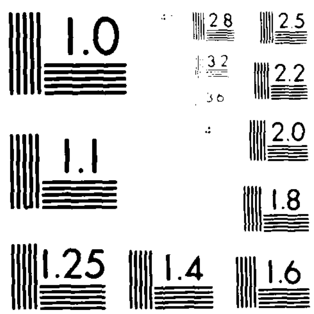
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Final Report

LEVEL II

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AD A097233

A Total Systems Approach To Environmental Problems

SEASONAL ASSESSMENT OF THE RELATIONSHIP BETWEEN THE DISCHARGE OF THE TRINITY RIVER AND THE TRINITY BAY ECOSYSTEM

Prepared for

FORT WORTH DISTRICT, U.S. CORPS OF ENGINEERS

Contract No. DACW 63-73-C-0059

ECOSYSTEMS management

3600 Hulen Fort Worth, Texas 76107 (817) 731-3727
A part of Coastal Ecosystems Management Inc

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REPORT DOCUMENTATION PAGE

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Trinity River, Texas
Zoological Assessment

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Field studies of the seasonal assessment of the relationship between the discharges of the Trinity River and Trinity Bay ecosystem was to provide information for possible future controls in order to maintain normal biological productivity levels, botanical, zoological and water quality parameters. Overall biological productivity in a river-fed bay-type estuary is governed by a large number of environmental factors; local runoff and discharge of the river are two of the most important factors of water quality parameters. This study does not include monitoring all point sources of runoff water into Trinity Bay, so interactions of various

20. parameters cannot be determined. Changes can be clearly defined simply by relating changes observed in the bay to changes observed in the river and marshes. This study is one of three investigations concerned with Trinity drainage basin and its estuary; and, extends and supplements the previous part of this study.

3600 HULEN FORT WORTH, TEXAS 76107 817/ 11 3727

ECOSYSTEMS MANAGEMENT

Coastal Ecosystems Management Incorporated

25 August 1973

Colonel F. H. Henk, District Engineer
Fort Worth District
U.S. Army Corps of Engineers
P. O. Box 17300
Fort Worth, Texas 76102

Attention: Trinity Environmental Section

Dear Colonel Henk:

Transmitted herewith is the final report in fulfillment of Contract DACW 63-73-C-0059, entitled "Seasonal Assessment of the Relationship Between the Discharge of the Trinity River and the Trinity Bay Ecosystems."

This report was derived from field studies carried out during the period from December 1972 to June 1973 and was designed expressly to continue and complement the similar study performed for the Trinity Environmental Section under Contract DACW 63-72-C-0142, entitled "Environmental Study of the Trinity River Basin." Together these two reports yield data from an entire year of observations. The object of the investigations was to provide information for possible future controls in the Trinity River Basin, in order to maintain normal biological productivity levels in Trinity Bay.

This report is advisory and does not necessarily constitute the final project concept to be adopted and approved by the U.S. Army Corps of Engineers.

Very truly yours,

Robert H. Parker

Robert H. Parker,
President

RHP/DES:el
Enclosure

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SEASONAL ASSESSMENT OF THE RELATIONSHIP BETWEEN THE DISCHARGE OF THE TRINITY RIVER AND THE TRINITY BAY ECOSYSTEM.

9 FINAL REP[redacted]T.

Prepared for

FORT WORTH DISTRICT, U.S. CORPS OF ENGINEERS

15 Contract No. DACW 63-73-C-0059

"Ecological Survey Data for Environmental Considerations
on the Trinity River and Tributaries, Texas."

Prepared by

COASTAL ECOSYSTEMS MANAGEMENT, INC.

10 John E. Solomon [redacted] Gerald D. Smith

11 25 Aug 73 12 162

Coastal Ecosystems Management, Inc.
3600 Hulen Street
Fort Worth, Texas 76107

25 August 1973

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A great measure of thanks is also due to the staff members of Coastal Ecosystems Management, Inc. for their various contributions. These staff members, both present and former, include: John Alderson, Debra Arnold, Harold Bryant, James Hampton, Virginia Mauldin, Hubert Miller, and Kenneth Moore. We especially wish to thank Robert H. Parker, President of Coastal Ecosystems Management, Inc., for his critical review of the manuscript.

INTRODUCTION

The relationship between discharge of any river and its estuarine ecosystem, and especially Trinity River and Trinity Bay, is difficult to define. The number of variables, many of which are non-linear, is so large that reliable data for all of them is almost impossible. A considerable amount of data for some of these variables has been published and allows a definition of baseline conditions in Trinity Bay for the past 10 years (Stevens, 1962; Gloyna and Malina, 1964; U.S. Geological Survey, 1964, 1965; Trent, Pullen, Mock, and Moore, 1967; Culpepper, Blanton, and Parker, 1969; Pullen and Trent, 1969; Baldauf, von Conner, Holcombe, and Truesdale, 1970; Copeland and Fruh, 1970; Huston, 1971; Strawn (editor), 1972; Parker, Solomon, and Smith, 1972). There is an adequate body of literature on selected parameters in various rivers to allow a good definition of baseline conditions in other river ecosystems (White and Freese, 1959; U.S. Geological Survey, 1964-1971; Hughes and Leifester, 1965; Leifester and Hughes, 1967; Parker, Blanton, Slowey, and Baker, 1969; Dupuy, Manigold, and Schulze, 1970; Hahl and Ratzlaff, 1970; Blakey and Kunze, 1971). There are, however, very few studies relating the direct influence of a river on its bay type estuary. Nash (1947), Copeland and Moseley (1971), and Copeland, Odum, and Cooper (1972) all established that "community metabolism" in some lower Texas estuaries were raised following increased river flow above the estuaries. These authors measured respiration rates or phytoplankton volumes as indicators of community metabolism, but other physical-chemical parameters were not reported.

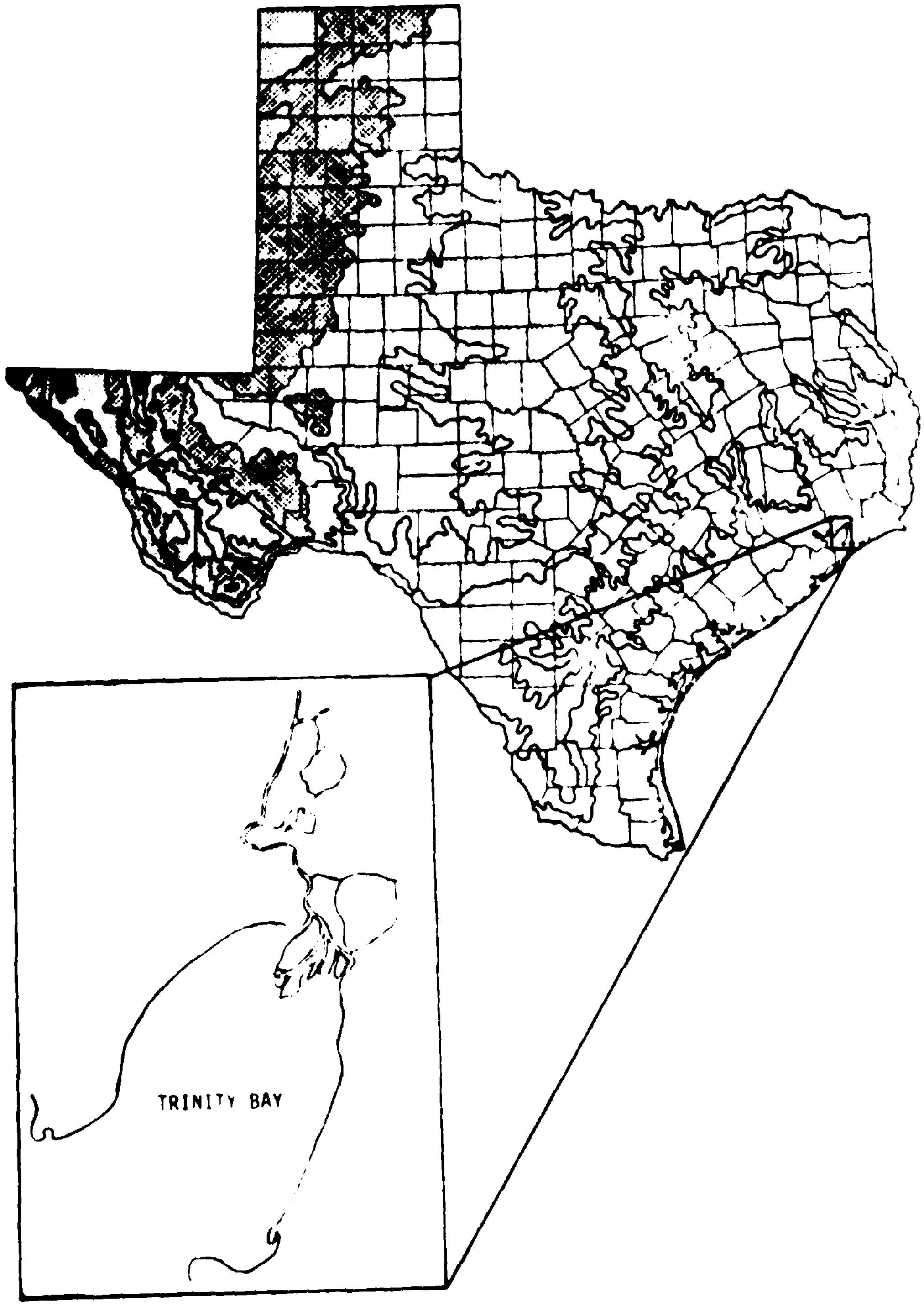
The Trinity River empties directly into Trinity Bay and also supplies considerable water to the marshes of the delta area and to the marshes extending approximately five miles along the northwest shore of the bay, west of the delta. These marshes, in turn, exert an influence on the water that passes through them, as well as contribute nutrients and organic matter to the bay.

Overall biological productivity in a river fed bay-type estuary, such as Trinity Bay, is governed by a large number of environmental factors. Local runoff and the discharge of the river are two of the most important factors with which many of the water quality parameters of the bay are directly correlated. In order to define adequately the effect of the Trinity River on Trinity Bay, certain kinds of studies or combinations of studies should be performed; including long term monitoring of the lower river and the bay, short term monitoring of the Trinity system along with other river-estuary systems (for comparisons), and modeling with existing data and computer models. Because of the short term nature of the contract under which this report is being submitted, Coastal Ecosystems Management, Inc. (C.E.M.) proposed to monitor the lower Trinity River, Trinity Bay, and selected areas in the marshes of the northwest side of the bay, through the winter and spring seasons of one year (1972-73). The data collected in this study plus the data presented in a previous study of the same area during the summer of 1972 (Parker, Solomon, and Smith, 1972) will cover almost one year of monitoring for the study area. The data consist of selected botanical, zoological, and water quality parameters and are arbitrarily restricted to the above mentioned study areas. This study does not include the monitoring of all the point scources of runoff water into Trinity Bay, so that the absolute interactions of the various parameters cannot be determined. It is proposed that relationships between ecological parameters in the bay, in the river, and in the marshes can be more clearly defined simply by relating changes observed in the bay to changes observed in the river and marshes. Normal patterns of distribution of the chemical, biological, and sedimentary variables measured during this study were depicted areally in the previous study (Parker, *et al.*, 1972). Repeating these areal plots each month would be repetitious and serve no real purpose.

This study is one of three investigations all concerned with the Trinity drainage basin and its estuary. The first study (Contract DACW 63-72-C-0142) reported in Parker, *et al.* (1972) was a short term assessment of the effect of the Trinity River on productivity in Trinity Bay. This present investigation (Contract DACW 63-73-C-0059) was designed specifically to extend and to supplement the previous study. The third investigation (Contract DACW 63-73-C-0016) was pursued concomitantly, with this one, by Stephen F. Austin State University. The Stephen F. Austin study concerned itself with the environmental factors of the Trinity River and its tributaries from Fort Worth to Trinity Bay.

Trinity Bay is located approximately 60 miles east of Houston, Texas, in the wet subhumid climatic zone (Parker, 1960). Trinity Bay is

Figure 1. Location of Trinity Bay and its relationship to the Texas Coast.


TRINITY BAY

the northeastern arm of the Galveston Bay complex (Fig. 1). The bay is approximately 14.8 miles long and 10 miles wide, has a mean depth of eight feet, and a volume calculated at 2.85×10^{10} $feet^3$ (Lankford, Clark, Warme, and Rehkemper, 1969). The area of fresh and brackish marsh considered in this study is approximately 12 square miles. The sampling station locations are illustrated in Figures 2 and 3, but not all stations were occupied on every sampling trip.

METHODS

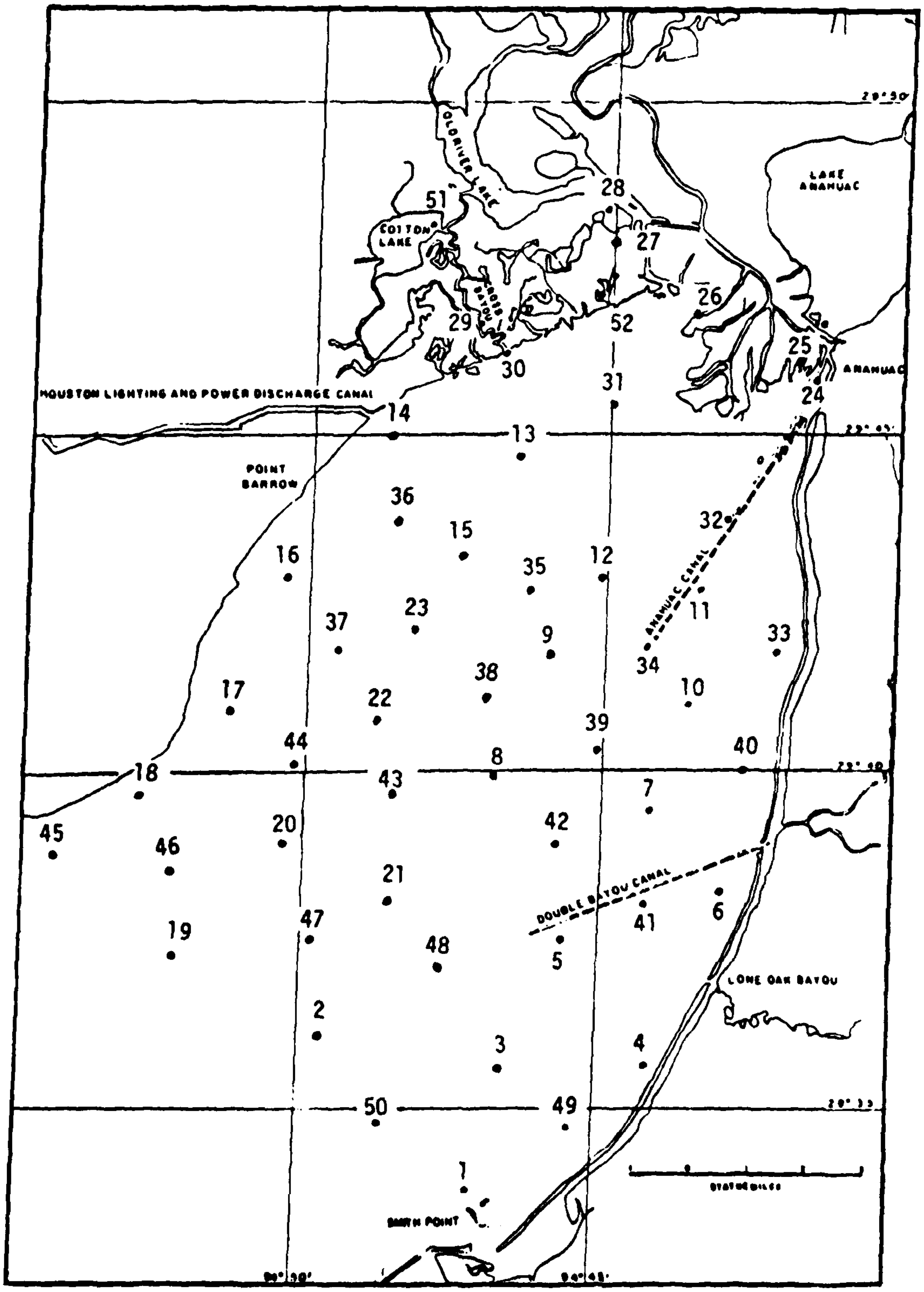
Field chemical measurements, not made *in situ*, were determined from surface and bottom water samples, collected with a 12 volt DC powered "Flotec" pump on the deck of the boat. Marsh station water samples were collected at mid-depth. Tygon tubing was used to connect the pump to various lengths of PVC pipe. The tip of the PVC pipe was sealed and had a large "foot" attached to prevent it from penetrating the sediments. The last 12 inches of pipe immediately above the foot had several small holes drilled in it to allow the water into the pipe at the selected depth. The pipe was flushed by pumping for at least one minute before any samples were collected.

Chemical-Physical Parameters

A Hydrolab Model 6D Surveyor was used to measure surface and bottom temperatures, dissolved oxygen, conductivity, pH, Eh, and depth. This self-contained *in situ* monitoring system uses a precision thermistor temperature probe; a membrane covered, passive polarographic probe for dissolved oxygen; a four electrode probe with constant temperature correction for conductivity; a liquid filled pH probe and a solid state reference electrode for pH; and a platinum electrode for oxidation-reduction potential (Eh). Back in the laboratory, the oxygen solubility readings were corrected with the conductivity data that were measured simultaneously. The conductivity readings were then converted to salinity values. A Hach Chemical Company portable engineers laboratory (Model DR-EL) was used in the field to determine hydrogen sulphide in bottom water and turbidity of surface waters.

Nitrogen values given in this report represent the sum of nitrate plus nitrite forms and were measured with the Hach portable laboratory using a modified diazotization method. Phosphate values representing only orthophosphates were measured with the Hach portable laboratory using a stannous reduction method. Sulphate values were determined with the Hach portable laboratory using a turbidimetric method. Total organic carbon values were determined on a Beckman 44 total organic carbon analyzer using 200-microliter size samples. The total organic carbon (TOC) method involves the vaporization of all carbon in the sample to CO_2, the CO_2 then being carried to an infrared analyzer sensitized to measure CO_2. When the instrument is calibrated with carbonate controls, the resulting peaks give total carbon and inorganic or carbonate carbon. Subtracting the carbonates from total carbon yields total organic carbon. All metal ion determinations, except mercury, were done on a Perkin-Elmer Model 303 atomic absorption spectrophotometer, while mercury concentrations were analysed on a Jarrel-Ash atomic absorption spectrophotometer.

Figure 2. C.E.M. station locations within Trinity Bay region.



OLD RIVER LAKE
LAKE ANAHUAC
COTTON LAKE
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
POINT BARROW
ANAHUAC CANAL
DOUBLE BAYOU CANAL
LONE OAK BAYOU
SMITH POINT
STATUTE MILES
29°50'
29°45'
29°40'
29°35'
94°50'
94°45'
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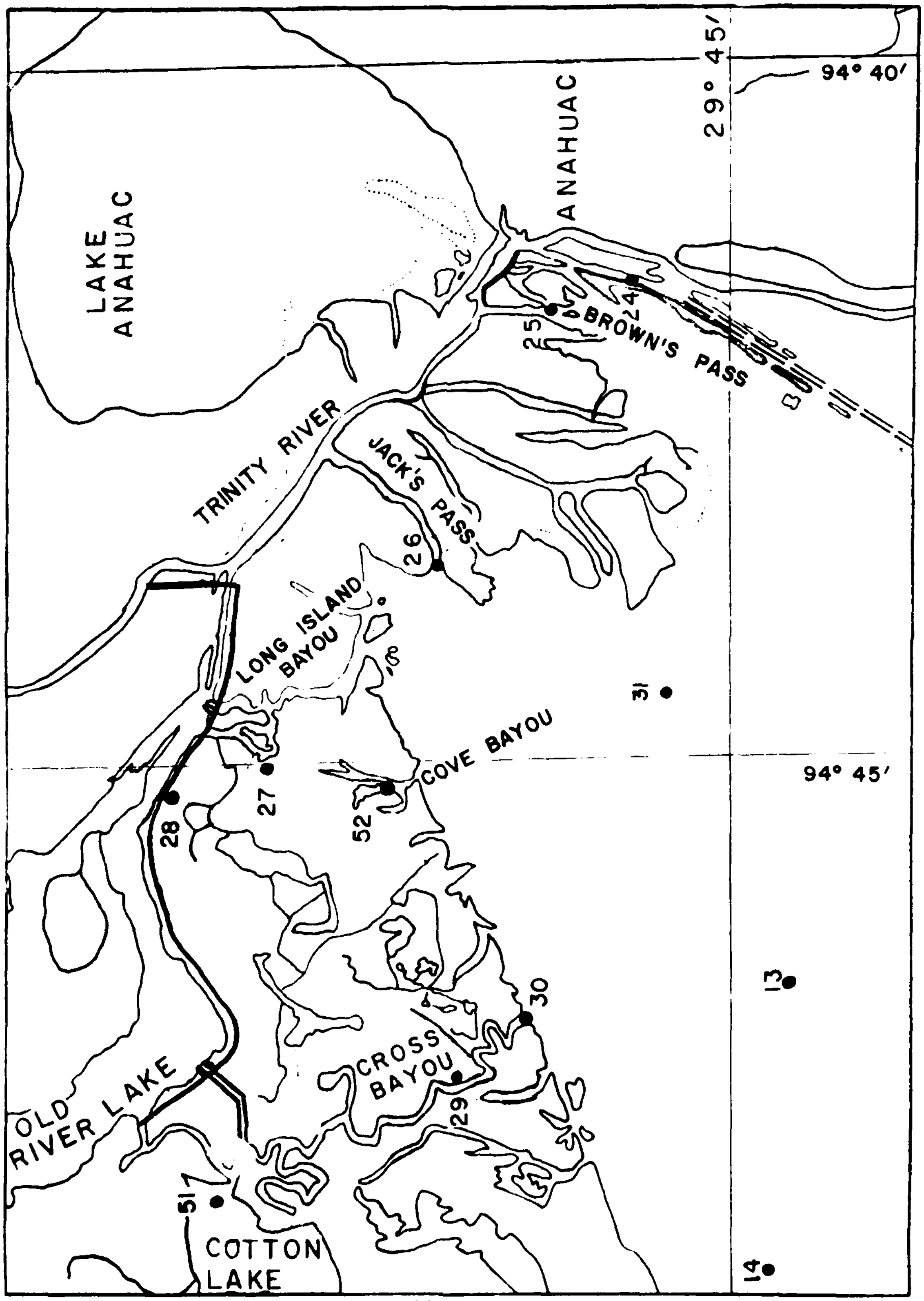
Figure 3. C.E.M. station locations within Trinity Bay marsh region.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ANAHUAC
29° 45'
94° 40'
24
25
BROWN'S PASS
TRINITY RIVER
JACK'S PASS
26
LONG ISLAND BAYOU
31
COVE BAYOU
94° 45'
27
52
28
13
30
CROSS BAYOU
29
OLD RIVER LAKE
51
COTTON LAKE
14

Biological and Sediment Parameters

Most probable numbers of coliform bacteria were counted from bottom water samples using the Millipore filter technique. Total bacterial populations were counted from the top centimeter layer of sediment grabs and from bottom water samples. These direct counts were made following the filtering of water samples and homogenizing aliquots of sediment samples and 24-hour incubation in MF-Endobroth culture dishes. Counts were made using phase microscopy.

Plankton samples for total counts of plankton were obtained with a 12-inch diameter, number 25 mesh plankton net, which was towed at one knot for five minutes. Plankton population counts were determined with the Whipple counting cell according to the drop sedimentation method of Standard Methods for the Examination of Water and Wastewater (1965). Chlorophyll determinations were carried out on surface water samples using a Coleman Spectrophotometer Model 6/20. Chlorophyll-a productivity was determined by taking two liters of surface water and fixing one liter immediately with Formalin, incubating the other for 24 hours in a water bath at the water temperature at the time of collection, fixing the second liter with Formalin, and comparing the amounts of chlorophyll-a in the two samples. This method negates the diurnal temperature effect and yields higher values than *in situ* incubation, which was impossible in this study.

Random samples of the various marsh vegetation were collected at selected stations in the marshes. Collection of a vegetation sample involved throwing an aluminum frame, that was built so that its perimeter enclosed one-half square meter, into the area to be sampled. The frame was then pressed to the ground and all vegetation inside it was clipped off at ground level. This vegetation was later identified, dried, and its dry weight recorded in the laboratory. The method and analyses generally followed those of Brown (1954).

Quantitative samples of benthic organisms were obtained with a 1/25 m^2 Van Veen grab sampler. The mud samples were washed through a 250 micron mesh screen in the field and fixed with 10 percent Formalin. In the laboratory, the preserved samples were washed through a series of U.S. Standard screens with mesh openings of 4.0 mm, 2.0 mm, 1.0 mm, 0.5 mm, and 0.25 mm. The organisms in each of the fractions were methodically picked by hand, identified, and counted under dissecting microscopes. Diversity indices for approximately 80 standard easily identified taxa were calculated by using a modification of the Shannon-Weaver diversity index. The formula used is:

$$H'' = -\sum_{i=1}^{s} \frac{n_i}{N} \log \frac{n_i}{N}$$

n = number of organisms of the ith species
N = total number in the sample

Diversity indices for the previous investigation by C.E.M. (Parker, et al., 1972) were recalculated, using this formula, so that all data from August, 1972, to date could be compared.

Epibenthos and nekton were sampled in the bay with a 3.5-meter otter trawl with a stretched mesh opening of 356 mm (1 3/8 in.), and a cod end cover of 160 mm (5/8 in.) stretched mesh, which was towed at two knots for 10 minutes. The epibenthos and nekton in the marshes were sampled by a

9.15-meter seine with a mesh opening of 160 mm (5/8 in.) which was dragged over an area approximately 4 meters x 10 meters, either parallel to shore or in a large arc out from and back to the shore. All organisms caught in either the trawl or the seine were fixed in 10 percent Formalin and later identified and measured in the lab.

Cores of the bottom sediments, for both bacterial studies and sediment size analysis, were obtained by pushing lengths of cellulose butyrate core liner into the sediments, stoppering the liner, and slowly removing the core barrel from the bottom. Vacuum in the stoppered core barrel prevents the surface of the core from being disturbed by water flushing. The cores were kept upright and placed on ice for shipment back to the laboratory. Sediment analyses included sieving of the coarse fraction (greater than 62 microns) and hydrometer analyses of settling velocities for the fine fraction (less than 62 microns). The Bouyoucos hydrometer method, as described by Wilde, Voigt, and Iyer (1964), was used with a modification of time intervals to determine particle size of sediments. The percents sand, silt, and clay for each sample were calculated and each sample was classed according to sediment analysis as described by Shepard (1954). Other systems of particle size classifications, such as the U.S. Department of Agriculture Soil Classification and the Unified Soil Classification, as used by the Corps of Engineers and Bureau of Reclamation, were not used because nomenclature used for the analyses of dry soils are not analagous to those used for saturated aquatic sediments.

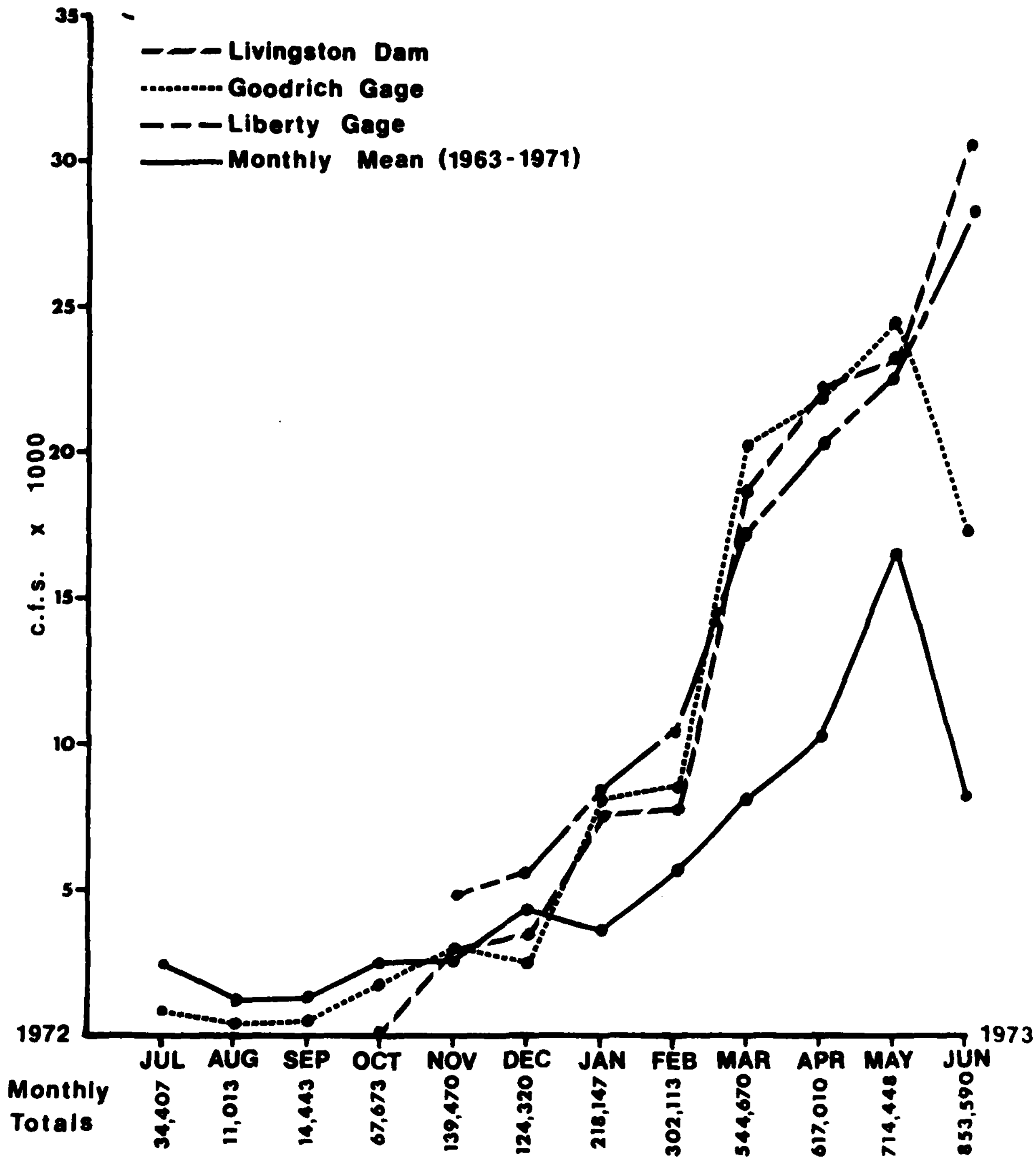
RESULTS OF FIELD AND LABORATORY ANALYSES

The study period covered by this report was from December 1972 to June 1973. The specific sampling periods were: December 18-23, 1972; February 5-10, March 19-24, May 6-11, and June 11-15, of 1973. We have included the data from the August 1972 sampling trip from an earlier investigation of the same area (Parker, *et al.*, 1972) in all discussions of collected data.

The August data represents the summer extremes of conditions, while the data from December and February represent winter conditions, and data from March, May, and June represent spring conditions. Most samples were collected between 8 a.m. and 2 p.m.

The basic purpose of this investigation is to relate the changes observed in Trinity Bay and its marshes with changes in the flow of the Trinity River; thus, it is necessary to first depict the river flow during the study period (Fig. 4). As is indicated by this graph, it was an exceptionally wet spring with record rains in both the upper and lower portions of the Trinity drainage basin. Dallas and Tarrant counties recorded rainfall of 112 percent of normal in the five-month period ending May 31 (Texas Water Development Board, 1973). Even heavier rains occurred on the coast, with Houston, Galveston, and Beaumont experiencing heavy flooding during the second week of June. The lowest flow of the study period occurred during August 1972. We consider it a stroke of luck that such wide extremes of flow occurred during the study period because the potential for change of conditions related to the river was very great.

Figure 4. Mean and total monthly *Trinity River discharges during the* study period of July 1972 through June 1973.



Livingston Dam
Goodrich Gage
Liberty Gage
Monthly Mean (1963-1971)
c.f.s. x 1000
35
30
25
20
15
10
5
1972
1973
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Monthly Totals
34,407
11,013
14,443
67,673
139,470
124,320
218,147
302,113
544,670
617,010
714,448
853,590

Water Quality Factors

Temperature

The range of water temperatures is shown on Figure 5. Highest water temperatures occurred in August 1972, reaching 29°C in the bay. The lowest temperatures of 5.5°C were observed in December. From December onward, water temperatures increased gradually and quite evenly until the study terminated in June, when temperatures almost reached those of the previous August. None of the observed temperatures were very close to the extremes, which range from 2.0° to 35°C, that have previously been recorded for Trinity Bay (Parker, 1960). Because of extremely low air temperatures in March, the mean surface water temperature was lower than the mean bottom water temperature, but during all other trips the mean bottom temperature was lower than the mean surface temperature.

Higher mean water temperatures were recorded in the marshes during August, December, and February. Lower mean water temperatures were recorded in the marshes during the months of March, May, and June. Marsh stations showed greater temperature extremes because waters are shallower and not well mixed.

Dissolved Oxygen (DO)

Dissolved oxygen values observed during the study period are graphed on Figure 6. The saturation of dissolved oxygen in water is temperature dependent, and by comparing Figures 5 and 6 it can be seen that DO is inversely correlated with the water temperatures. Dissolved oxygen levels ranged from 3 ppm in August to 14.1 ppm in February. Values below 4 ppm

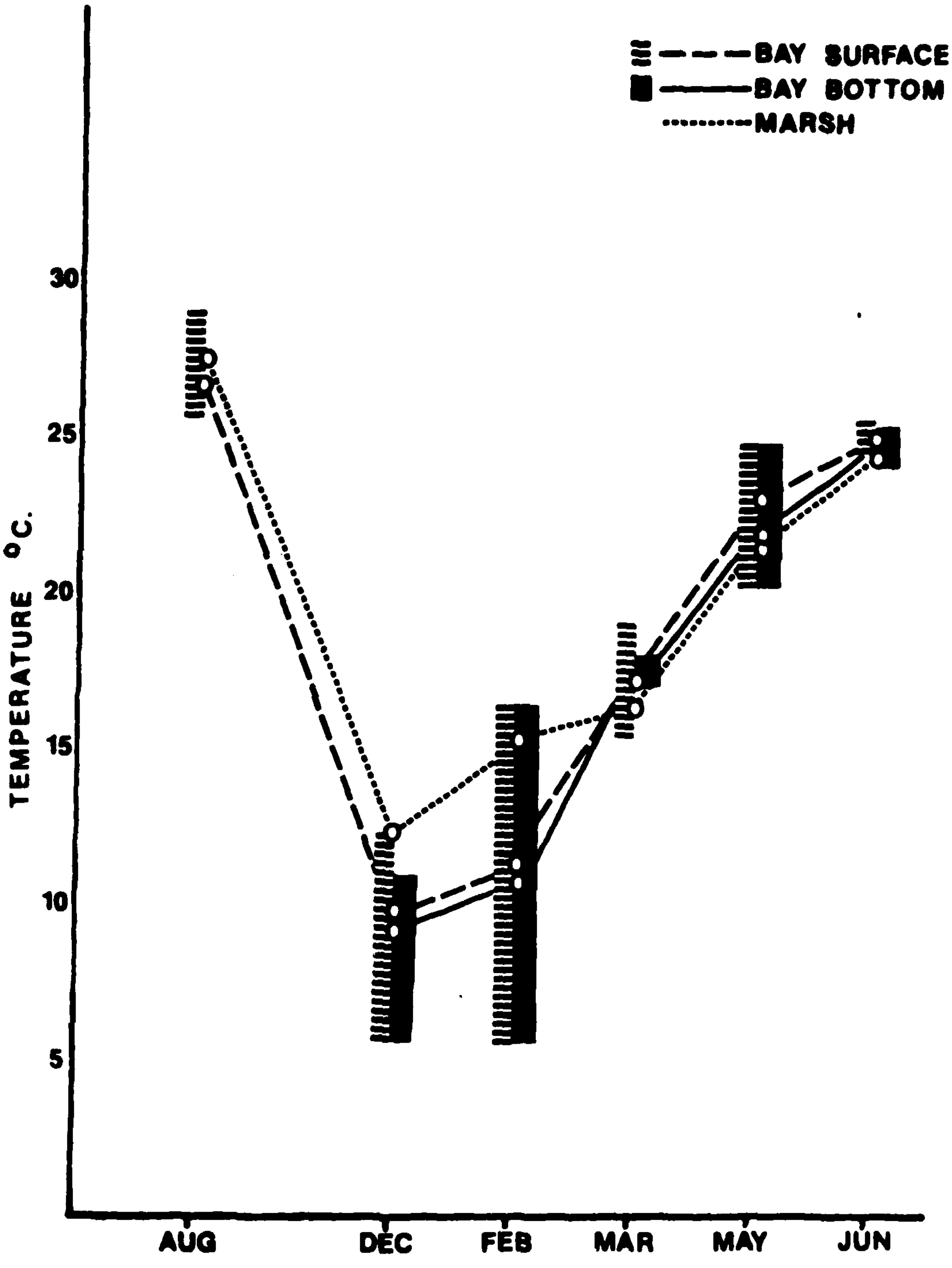


Figure 5. Mean and extremes of water temperatures as average surface and bottom values for sampling periods August 1972-June 1973, within Trinity Bay and delta marshes.

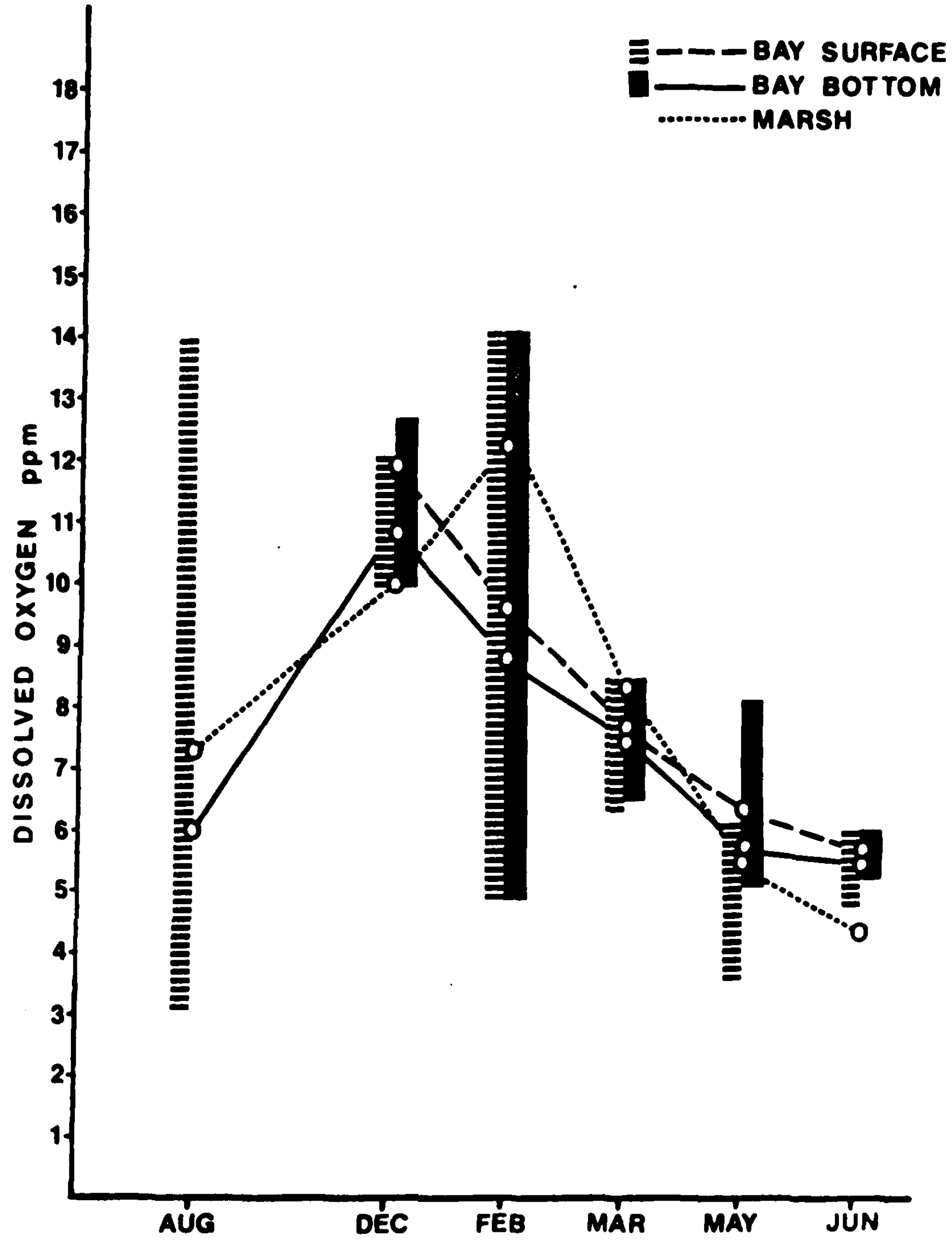


Figure 6. Mean and extremes of dissolved oxygen as average surface and bottom values for sampling periods August 1972-June 1973, within Trinity Bay and delta marshes.

were recorded only in August and May. The Environmental Protection Agency has indicated 4 ppm to be the minimum necessary to sustain warm water biota (Environmental Protection Agency, 1971), so that dissolved oxygen cannot be considered a limiting factor in the ecology of Trinity Bay.

In August and February, a wide range of DO concentrations were observed, while during the other months, quite narrow ranges of values occurred with almost all stations having values within 3 or 4 ppm of one another. Wind and wave action in Trinity Bay are considerable and could easily account for the relatively even distribution of dissolved oxygen. Additionally, no reducing conditions were observed in the sediments nor was any production of H_2S observed, indicating little biological oxygen demand which might have an effect on the areal distribution of dissolved oxygen.

Salinity

The salinity of an estuary is the one factor affected most by river discharge of fresh water. The salinity values for the bay and marshes during the study period are graphed on Figure 7.

The effect of fresh-water flow into Trinity Bay can be seen by comparing Figures 4 and 7, where it is apparent that the two factors are inversely proportional. Salinities were beginning to increase in June even though river flow was still increasing. The salinity increase may reflect higher air temperature in June with an increased evaporation rate. The salinity regime of this bay has previously been cited as 4 to 10 $^{o}/oo$ (Renfro, 1960) and 1 to 10 $^{o}/oo$ (Parker, 1960). The salinities of August

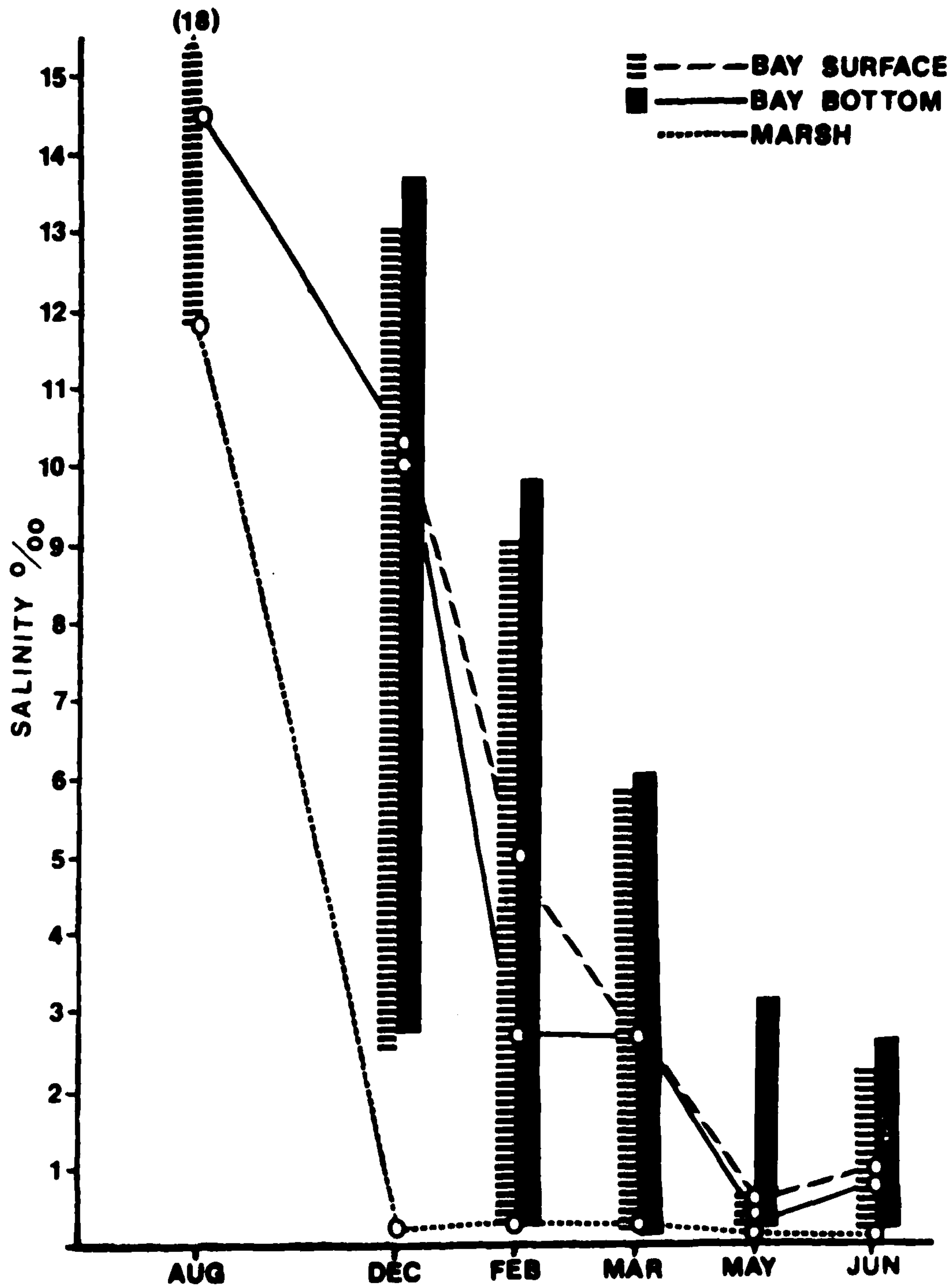


Figure 7. Mean and extremes of salinity as average surface and bottom values for sampling periods August 1972-June 1973, within Trinity Bay and delta marshes.

1972 exceeded 18 $^{o}/oo$ and the mean salinities of May and June 1973 were less than 0.5 $^{o}/oo$. During the study period, bay salinities ranged from half the normal oceanic salinity to essentially fresh water, an extreme range of values for the biota of any estuary to endure.

Hydrogen Ion Concentration (pH)

The pH values observed during the study period were remarkably constant. The range of values for the various months is as follows: August, 7.0 to 8.5; December, 8.0 to 9.1; February, 6.5 to 8.8; March, 6.8 to 8.9; May, 7.3 to 8.4; and June, 7.1 to 8.4 pH units. The variation in mean values during the study is shown on Figure 8. The range of values for the months of February and March was over 2 pH units while all other months had ranges of values less than 1.5 pH units. It was during February and March that minor problems were encountered with the pH and Eh subsystem of the Hydrolab sampling module and the increased range of values for the two months may be nothing more than decreased sensitivity of the instrument.

The literature on the pH of estuarine waters contains pH ranges of 6.6 to 9.1 (Blakey and Kunze, 1971), and 6.2 to 9.4 (Travis, 1972). The "normal" range of marine pH is usually 7.8 to 8.3 while the Trinity River at Romayor had a pH range of 7.0 to 9.1 during the 1970 water year (U.S. Geological Survey, 1973), and a range of 7.0 to 8.6 throughout its length in September, October, and November of 1972 (Coster, Fisher, Hall, Jones, McCullough, and Nixon, 1973).

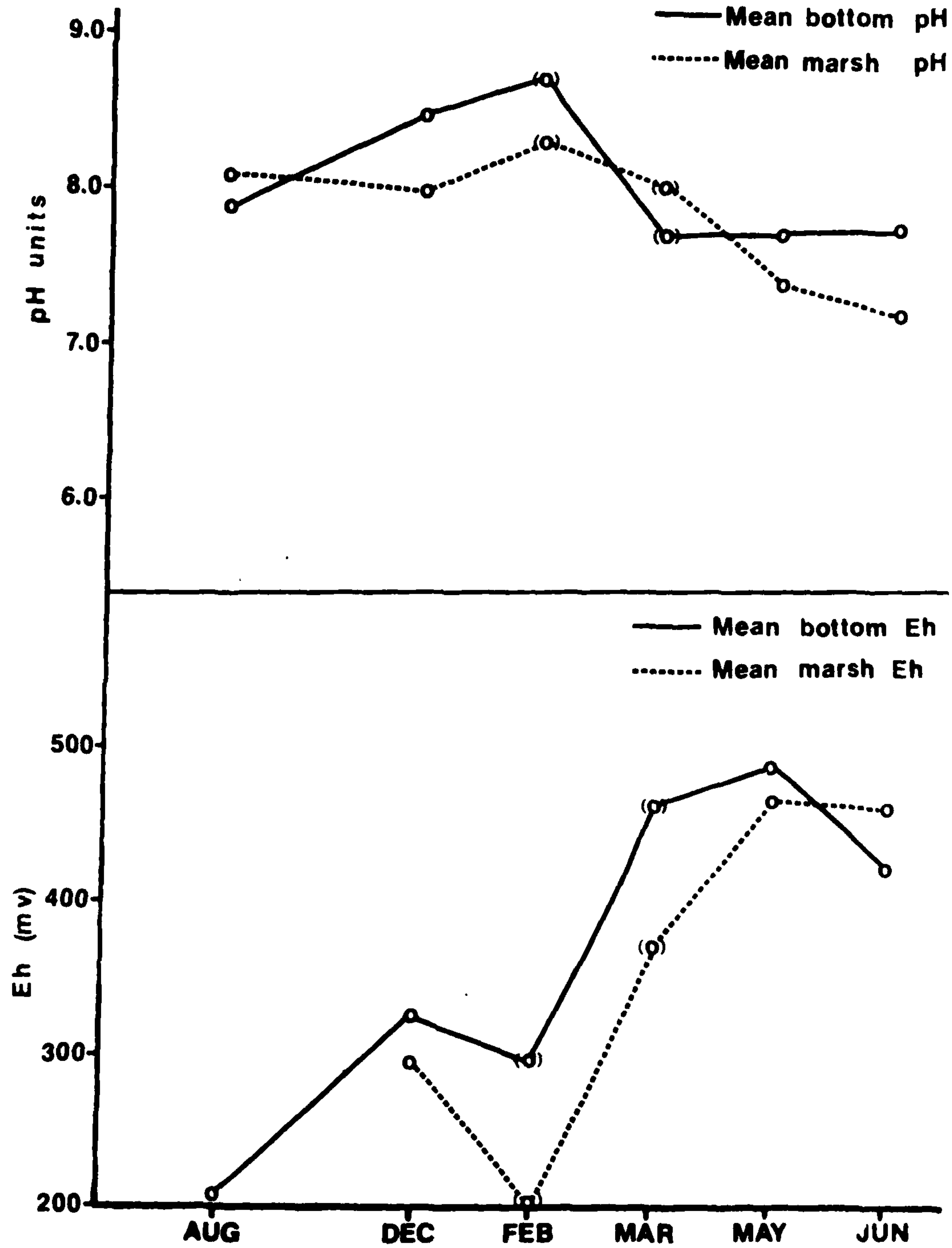


Figure 8. Mean pH and Eh values in Trinity Bay and marshes for the sampling period August 1972-June 1973.

Reduction-Oxidation Potential (Eh)

The reduction-oxidation potential of solutions is related to pH and is a measure of the tendency of ions to lose or gain electrons under given conditions (McCrone, 1972). The reduction-oxidation potential was measured at all bay stations at the surface and the bottom and at mid-depth in the marshes. Reduction-oxidation potential data for the months of February and March are suspect because of the above mentioned instrument problems in the pH-Eh subsystem. The range of values for the various months is as follows: August, +129 to +259 millivolts (mv); December, +294 to +394 mv; February, +51 to +469 mv; March, +49 to +1049 mv; May, +429 to +674 mv; and June, +379 to +459 mv. A graph of the mean values is shown on Figure 8. The surface and bottom values were always within a few millivolts of one another during all months. No reducing conditions (negative Eh's) were ever observed in the water mass of the bay. The mean redox-potential gradually increased from August through May and then decreased in June. The fact that only positive values were observed indicates that the conditions at the sediment-water interface will not be limiting to benthic invertebrates. Culpepper, *et al.* (1969) observed Eh values of from +260 to +320 mv in the lower portions of Cedar Bayou and Parker, *et al.* (1969) recorded values of from +199 to +350 mv throughout the Colorado River estuary. Both areas had abundant bottom faunas.

Hydrogen Sulphide (H_2S)

Water samples were analyzed for H_2S in August, December, and February. Hydrogen sulphide is a highly toxic gas given off by the action of anaerobic bacteria in sediments with organic carbon content. Its presence is limiting to benthic invertebrates--being a deadly poison in minute concentrations. At no time were values above 0.1 ppm recorded. This level is the lower limit of detection using the indicator test paper method and because of readings consistantly less than 0.1 plus concomitant high Eh values, it was decided to omit H_2S testing in subsequent trips and rely solely on Eh data as an indicator of reducing conditions.

Turbidity

The turbidities measured during this investigation are graphed on Figure 9. The waters of the bay were quite clear in August, but not again until June. The range of values was small in August 1972 and June 1973, but was quite consistantly large from December until May. As turbidity is a very ephemeral thing and can change rapidly from hour to hour, depending upon currents, winds, and waves, it is difficult to relate to seasonal changes. The Jackson scale of values for turbidity is 0-500 with 500 Jackson Turbidity Units indicating zero penetration of light into the water. The observed turbidities never exceeded 50 percent of the scale, or 250 JTU. The marsh stations and bay stations exhibited similar patterns of turbidities during the seasonal changes, with the exception of the month of March when marsh turbidities were considerably lower than those of the bay. During the months of September, October, and November of 1972, Coster, *et al.* (1973) measured turbidities in the lower half of the Trinity River ranging from 5 to 220 JTU's.

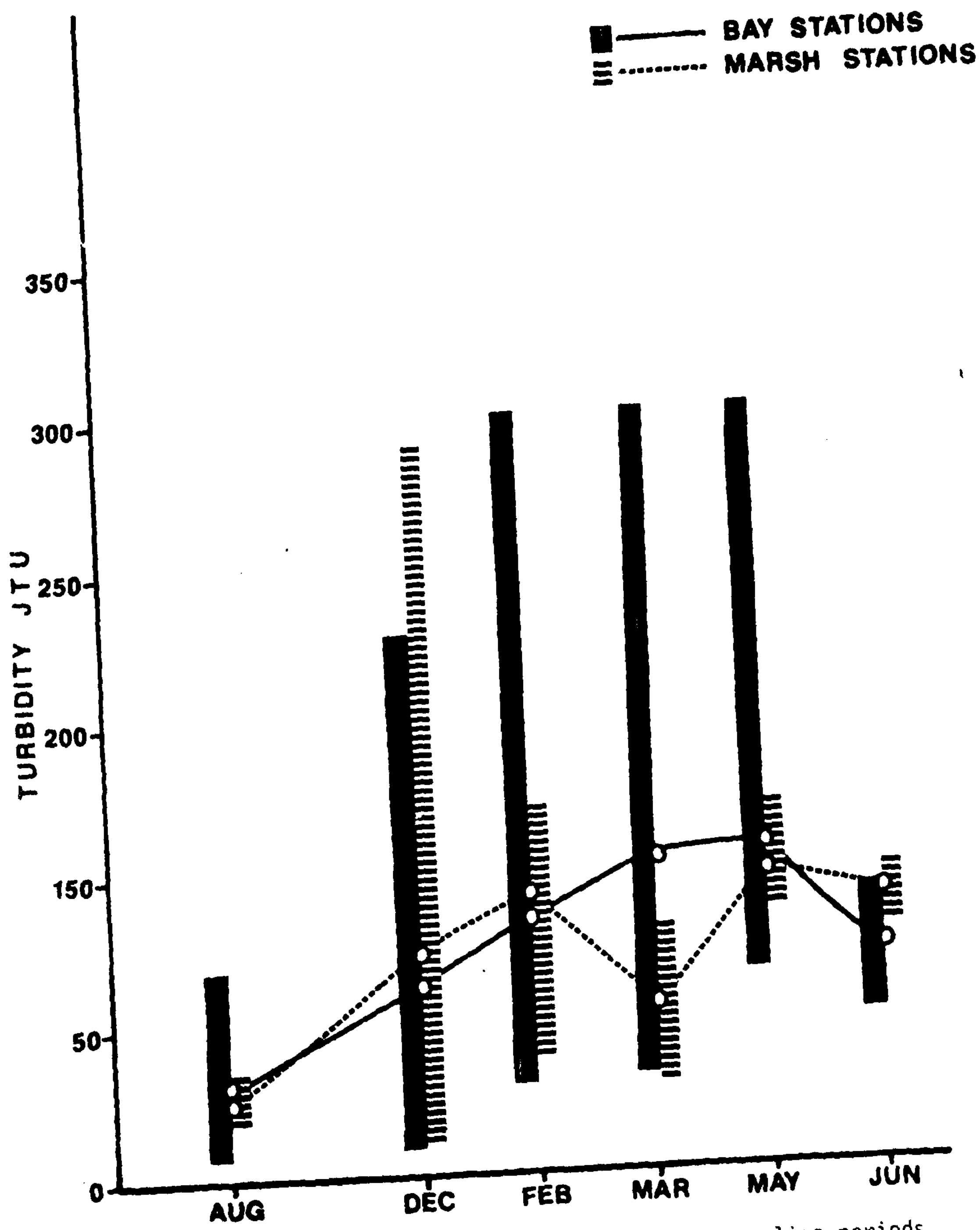


Figure 9. Mean and extremes of turbidity values for sampling periods August 1972-June 1973, within Trinity Bay and delta marshes.

Metallic Ion Concentrations

The seasonal concentrations of the various metallic ions from water samples are displayed on Figure 10. Mercury is one of these metals that has received much publicity as a health hazard to man and other animals, as animals have the ability to concentrate this metal in their tissues at high enough levels to cause health problems. Mercury concentrations were very high in August 1972, then dropped dramatically in December 1972, and dropped again in February 1973 to a steady low level for the rest of the study period. In August 1972, lower levels of mercury were measured at the marsh stations than at the bay stations, while in December 1972, the situation was reversed. During the remainder of the study period there were no differences in marsh and bay values.

Lead and copper ions never occurred in concentrations above the level of detection of the atomic absorption spectrophotometer--*i.e.*, 0.1 ppm for each of these two ions--in Trinity Bay water samples. Hann and Slowey (1972) reported lead and copper in Trinity Bay sediments of 5 to 28 ppm, and 4 to 15 ppm respectively. Concentrations of metals in sediments, however, are consistantly greater than those in the water column.

The concentrations of zinc and iron were consistantly less than 1.0 ppm. Zinc was always lower than 0.05 ppm in concentration, but Black and Mitchell (1952) state that it never exceeds 0.02 ppm in natural conditions. The mean concentration of iron was always above 0.1 ppm, but showed a considerable increase to 1.27 ppm in June. Both zinc and iron are important in the biosphere and in their divalent ionic states have some similarity in their chemical properties (Curtis, 1972). Iron transports oxygen from air

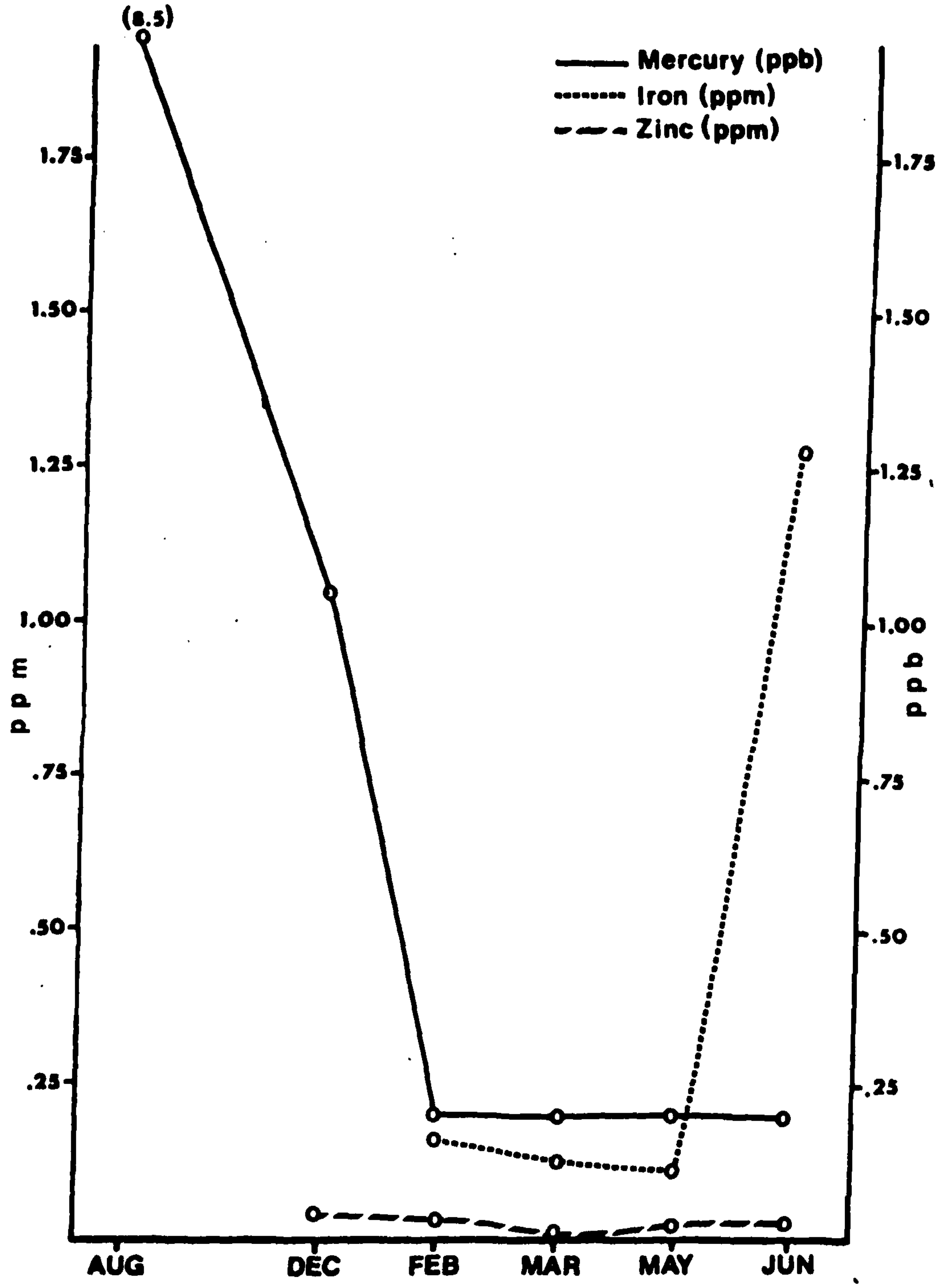


Figure 10. Mean mercury, iron, and zinc values at all stations for sampling periods August 1972-June 1973, within Trinity Bay and delta marshes.

or water to animal tissues, and in plants is necessary for the formation of chlorophyll. Marine concentrations of zinc are reported up to 0.01 ppm but estuarine concentrations could be higher because much zinc remains in solution (Curtis, 1972). Most river borne iron precipitates out when it reaches salt water, as marine levels of iron are reported as 0.003 to 0.03 ppm (Lepp, 1972). Perhaps the higher concentrations of iron in June in Trinity Bay were due to the extreme freshness of the water, delaying precipitation. Hann and Slowey (1972) reported iron and zinc in Trinity Bay sediments of 0.8 to 8.6 ppt and 10 to 60 ppm, respectively, which are three orders of magnitude greater than in the water column.

Magnesium and calcium are two relatively abundant ions in seawater and their ratio is often used as an indicator of water quality. The mean concentrations of the two ions and their ratios are shown on Figures 11 and 12. The normal Mg/Ca ratio for seawater is about 3.12, or 1.27 ppm of magnesium to 0.40 ppm of calcium (Sverdrup, Johnson, and Fleming, 1942). The concentration of calcium increases in fresh water, while magnesium normally decreases upstream of an estuary. These ions are important to animals for nerve conductance, ionic control systems, and their general physiological well-being. The Mg/Ca ratios of August 72 were considerably lower than what would be expected when salinities averaged near 15 $^{o}/oo$. The ratios were low because magnesium concentrations ranged only from 12 to 58 ppm. In December 1972, the Mg/Ca was significantly higher than what would be expected when salinities averaged near 10 $^{o}/oo$. The ratios were high because of extremely high magnesium concentrations of from 6 to 560 ppm. Calcium concentrations were quite similar for the two months, ranging

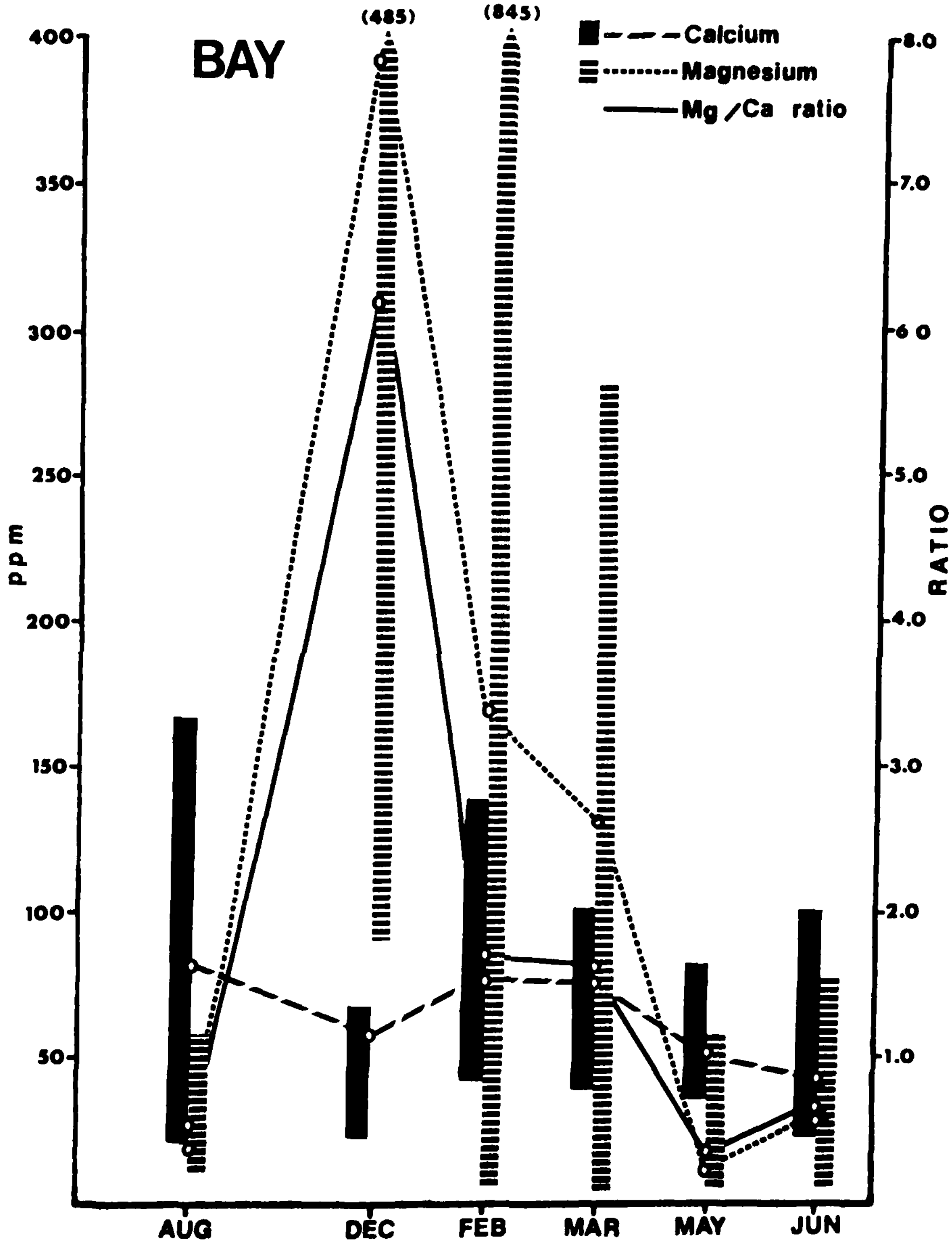


Figure 11. Means and extremes of concentrations of magnesium and calcium ions and the Mg/Ca ratio for Trinity Bay stations during the sampling period August 1972-June 1973.

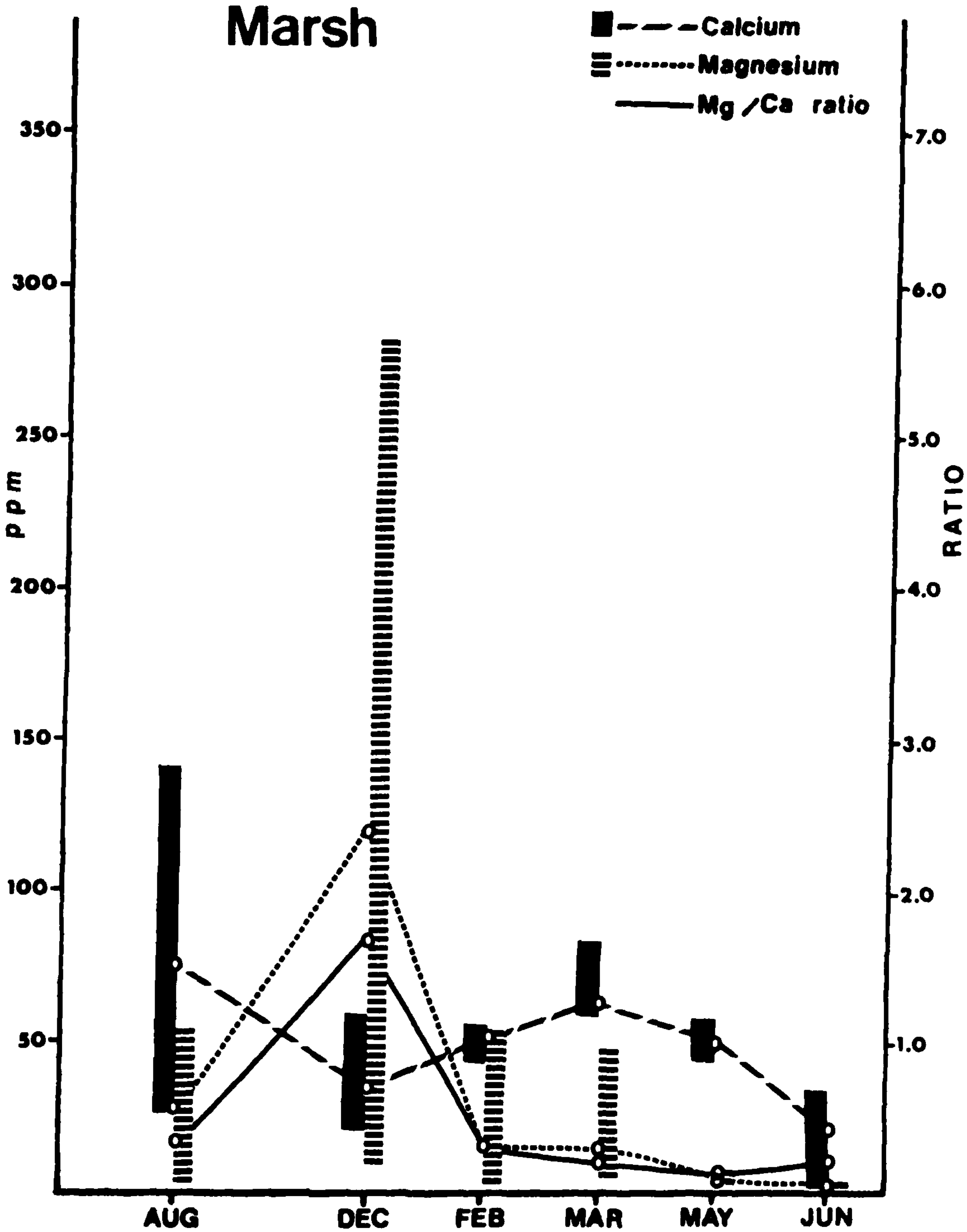


Figure 12. Means and extremes of concentrations of magnesium and calcium ions and the Mg/Ca ratio for the Trinity estuary marsh stations during the sampling period August 1972-June 1973.

from 20 to 168 in August and 20 to 68 in December. No explanation can be offered at this time for the tremendous fluctuation in magnesium ions. The ratio then decreased steadily until June when salinities again started upward. A comparison of Mg/Ca ratios on Figure 11 with the salinity fluctuations on Figure 7 shows a direct relationship because the Mg/Ca ratio is a direct function of the salinity gradient and the constancy of composition of seawater (Parker and Blanton, 1970). Magnesium/calcium ratios in fresh water are always less than 1.00, which was the case in May when the bay was nearly fresh.

Nutrient Factors

Biological productivity is largely governed by the nutrient budget of the ecosystem. This investigation did not evaluate the total nutrients entering Trinity Bay, but did monitor four indicators of the nutrient budget in the water mass that are very important to both phytoplankton and bacteria based food chains. These indicators are inorganic nitrogen, available phosphates, available sulphates, and total organic carbon.

Nitrate and Nitrite Ion Concentrations

The concentrations in water samples of nitrate plus nitrite-nitrogen measured during the study period are shown on Figure 13. The graphs for surface, bottom, and marsh stations appear very similar. In August there were very low concentrations in bottom water samples, but in all other months, all stations had over 2 mg/liter. Bottom water samples had a higher mean concentration of $NO_2^- + NO_3^-$ than surface water samples, during only two of the six sampling periods. The graphs indicate that

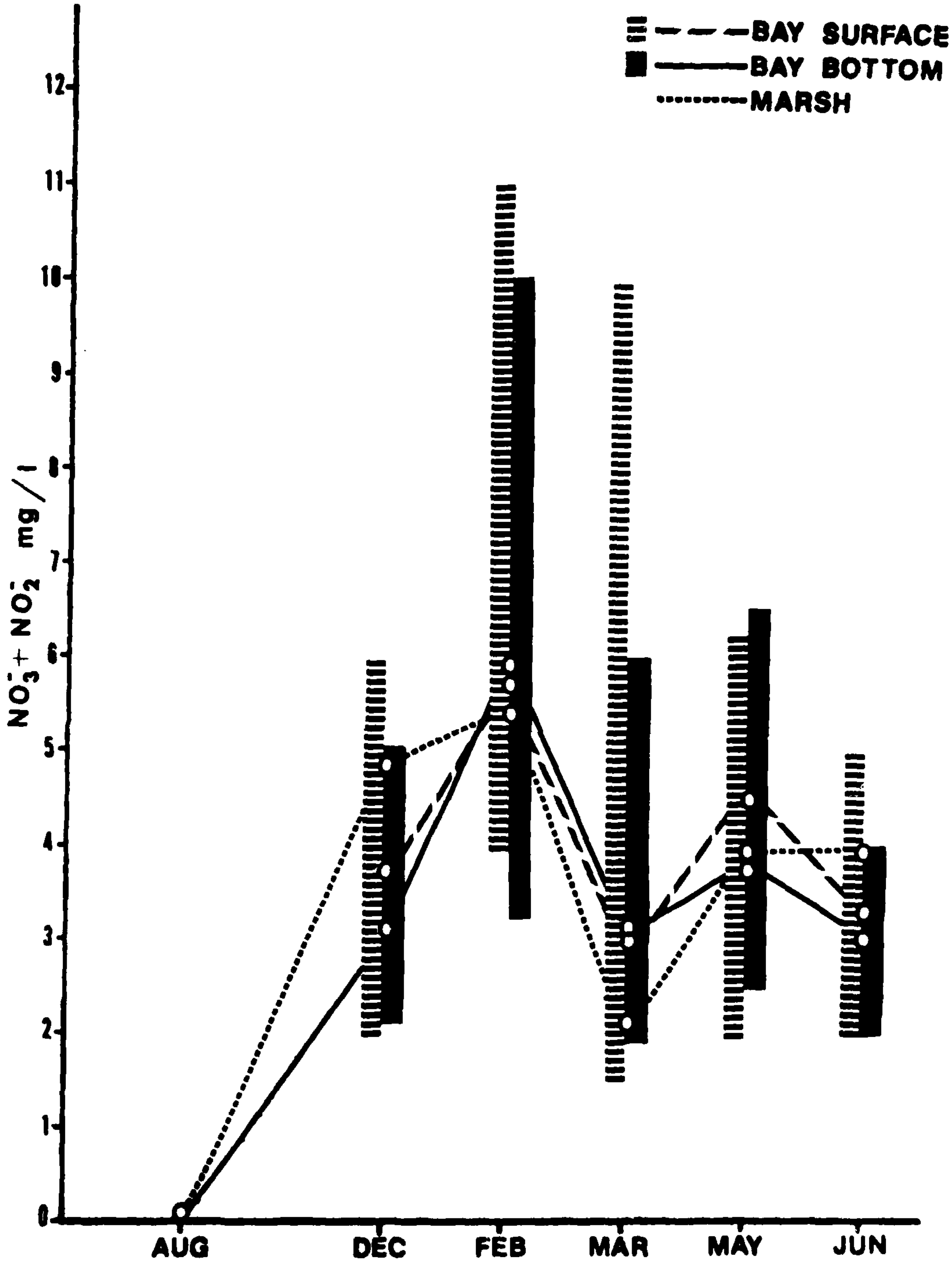


Figure 13. Mean and extremes of nitrate plus nitrite as average surface and bottom values for sampling periods August 1972-June 1973, within Trinity Bay and delta marshes.

since February there has been a trend toward lower concentrations of inorganic nitrogen. During September, October, and November 1972, Coster, *et al.* (1973) observed a range of $NO_2^- + NO_3^-$ from 0.005 to 10.875 mg/liter with a mean value of 2.43 for the entire length of the Trinity River. The U.S. Geological Survey (1973) cited a range of nitrates from 0 to 3.2 ppm, only at Romayor. These levels are similar to those reported by other authors for the Trinity and other rivers (Dupuy, *et al.*, 1970; Blakey and Kunze, 1971; Hahl and Ratzlaff, 1972). Estuarine levels of inorganic nitrogen fluctuate widely since a portion of the nitrates and nitrites come from runoff and thus fluctuate according to precipitation rates.

Orthophosphates

Phosphorus in its several forms is another important nutrient for plant growth. The observed values of orthophosphate during this study are shown on Figure 14. This graph indicates a general decreasing trend throughout the study period but with fluctuations of the mean value each month. Mean concentrations of orthophosphates were higher in bottom than surface water samples in all but one month. Samples from the marsh stations were the lowest in mean concentration of phosphates in all but one month.

Coster, *et al.* (1973) reported a wide range of orthophosphates, ranging from 0.25 to 49.00 ppm, in the entire reach of the Trinity River. The U.S. Geological Survey (1973) reported the mean value of total phosphorus at Romayor during the 1970 water year was 0.28 mg/liter. Values similar to those reported here have been cited by Dupuy, *et al.* (1970) at Romayor; Parker, *et al.* (1969) for the Brazos and Colorado Rivers; and Pullen, Trent, and Adams (1971) for Trinity Bay.

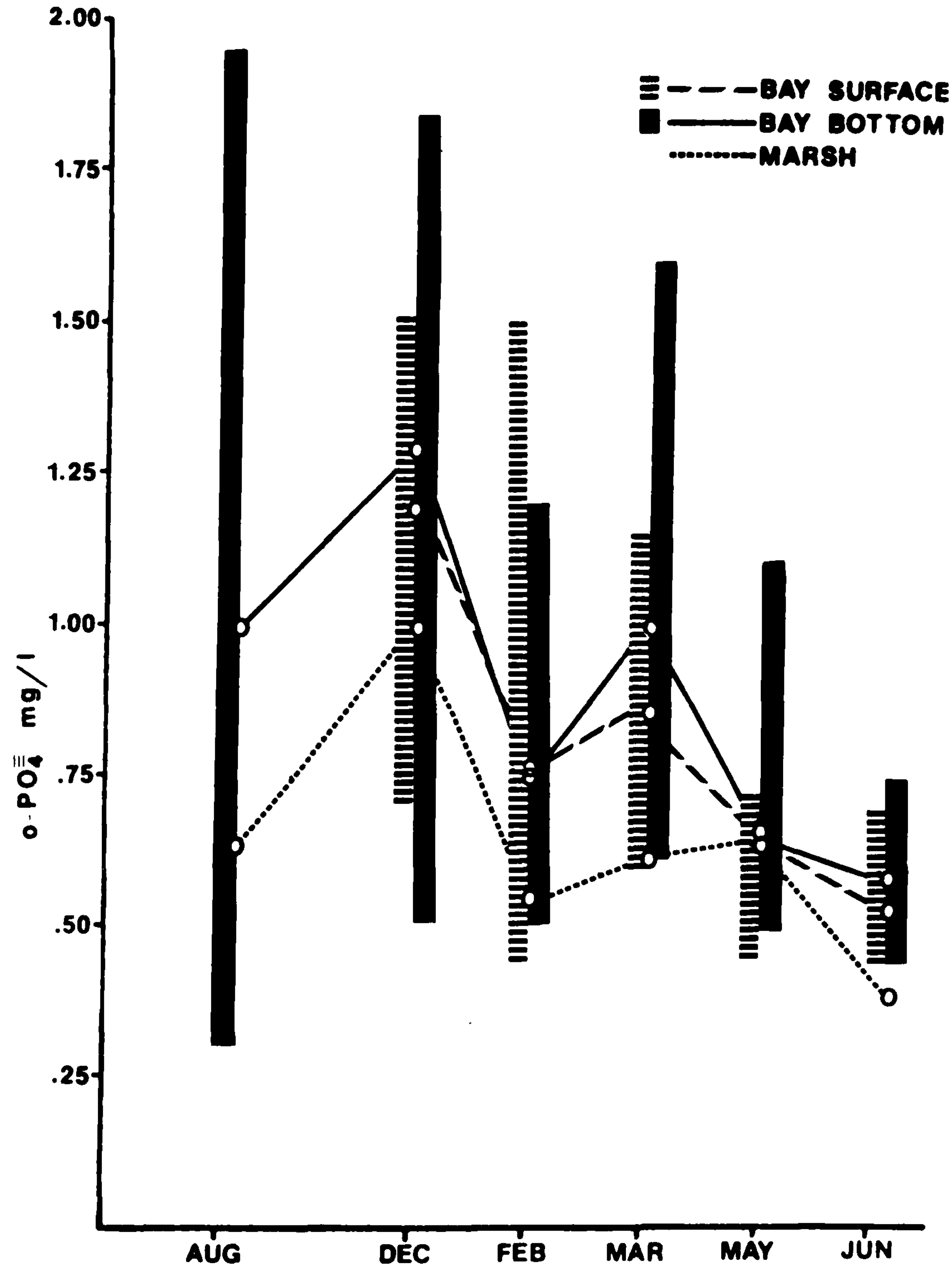


Figure 14. Mean and extremes of orthophosphates as average surface and bottom values for sampling periods August 1972-June 1973, within Trinity Bay and delta marshes.

Sulphates

Many microbial organisms and green plants obtain the sulfur needed for biosynthesis from the inorganic sulfate ion. Algae also satisfy their growth requirements for sulfur from the sulfate ion. The range of values of sulfate ion concentrations in the bay and marshes during the study period are shown on Figure 15. December showed the highest mean values of sulfates and the widest range of values for surface and bottom waters and at the marsh stations. Lower values were recorded for all subsequent sampling trips, there being a general decreasing trend for the rest of the study period. During all sampling periods, the marsh station samples had the lowest mean values for sulfates, surface water samples next highest, and bottom water samples always had the highest mean values.

The sulfates measured in this study are considerably higher than those for the Trinity River itself. Coster, *et al.* (1973) recorded a mean value of 114 ppm in the river during September to November 1972. The U.S. Geological Survey (1973) recorded a mean value of 46 ppm at Romayor for the 1970 water year. However, the sulfate values in the bay are much lower than in oceanic waters where sulfate ions are a major constituent and normally occur at the concentration of 2649 ppm (Sverdrup, *et al.*, 1942). The Texas State Department of Health monitors sulfates in Trinity Bay and has recorded values for 1970, 1971, and 1972 that yield a mean sulfate concentration of 990 ppm (Travis, 1972), considerably higher than those recorded during this study. The sulfates in the bay are a function of the influence of Gulf waters and tidal exchange; as can be seen by comparing salinities (Fig. 7) and sulfates (Fig. 15).

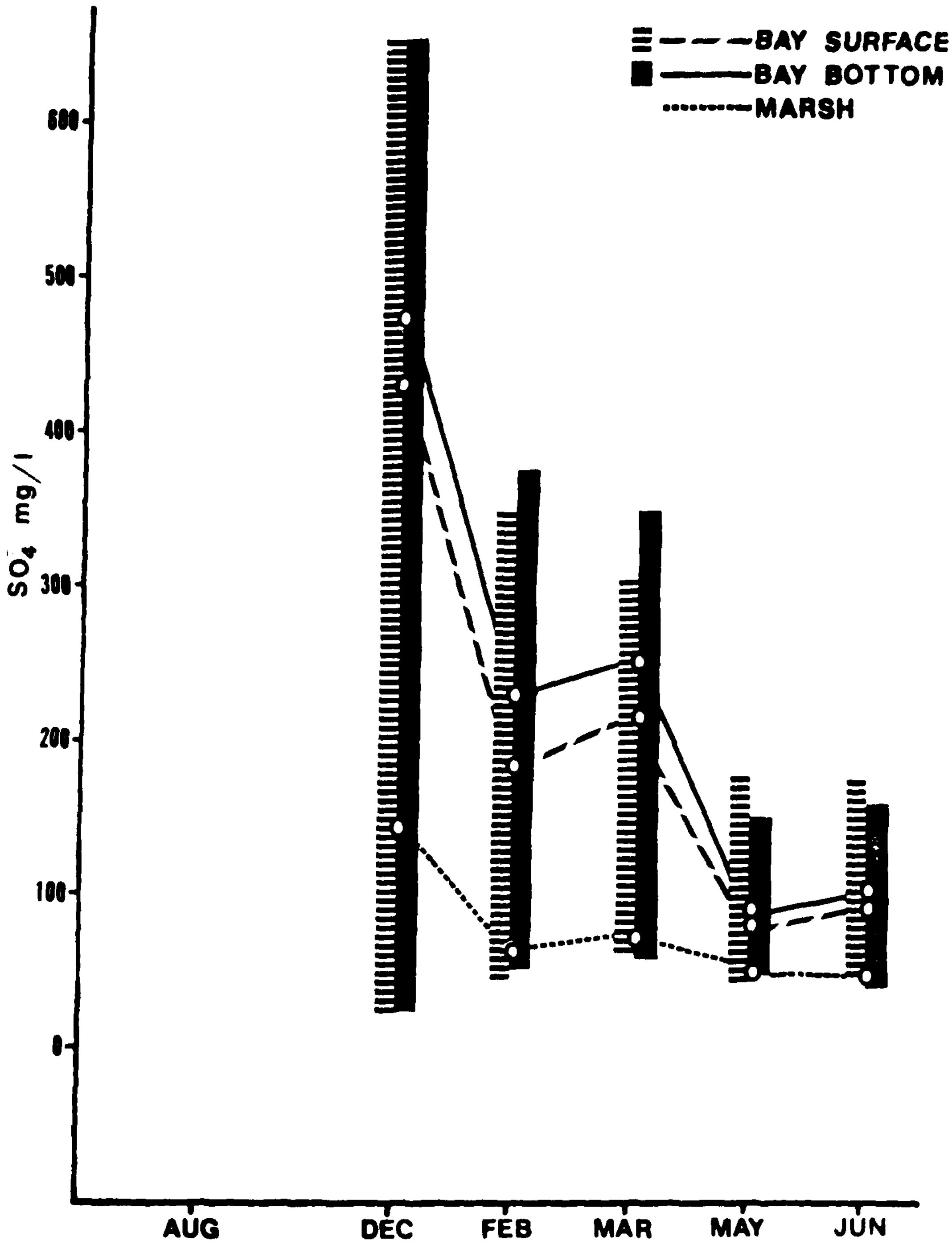


Figure 15. Mean and extremes of sulfate as average surface and bottom values for sampling periods August 1972-June 1973, within Trinity Bay and delta marshes.

Total Organic Carbon

Organic carbon is defined as those carbonaceous forms that were produced by photosynthesis. Most of the world's carbon is in the form of free or dissolved $CO_2^{\uparrow}$; but before it can be utilized by any living thing, the CO_2 must be converted via photosynthesis into one of the classes of carbohydrates. The measure of total organic carbon indicates the productivity of the biomass in the environment being sampled.

The amounts of organic carbon and the percentage of total carbon that was in organic form, found in the study area, are shown on Figure 16. Organic carbon amounts were highest in August 1972 and lowest in December 1972. The amounts of organic carbon remained relatively constant, between 8 to 10 ppm, for the late winter and spring period from February to June 1973. The graphs of surface, bottom, and marsh water carbon values all appear very similar. In the graph of the percentages of total carbon which was organic (Fig. 16), there shows a striking increase in the percentage of organic carbon throughout the study. The increase in the percent organic carbon correlates well with the increase in river discharge. In August of 1972, when the mean amount of organic carbon was highest, the proportion of mean organic to total carbon present was at its lowest; i.e., less than 20 percent of the total carbon was organic. In all the following sampling periods, a greater and greater percentage of the mean total carbon was organic. Sverdrup, *et al.* (1942) observed samples from Puget Sound, Washington, with 11.3% organic carbon and 88.7% inorganic carbon, although the total amounts of carbon in those samples were very low (0.1-0.4 mg-atoms/liter). Wilson (1963) observed organic carbon in the south of Trinity Bay in concentrations of 6.7 to 7.5 mg/liter. The increased

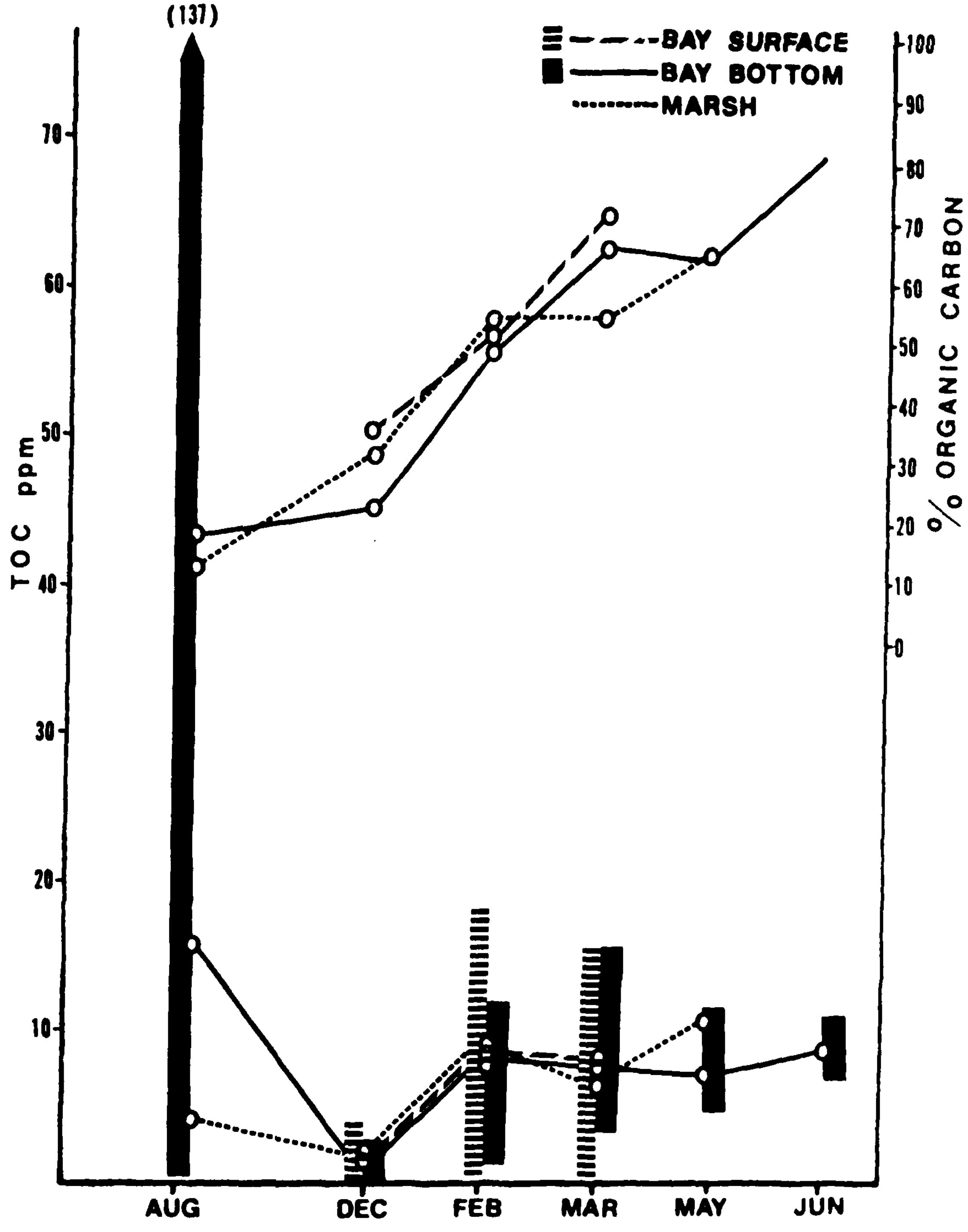


Figure 16. Organic carbon values versus percentage of total organic carbon for sampling periods August 1972-June 1973 within Trinity Bay and delta marshes.

percentages observed may possibly reflect large amounts of organic matter, which are not assimilated into the food chain for other reasons, being carried into the bay with the Trinity River flood waters.

Biological Factors

Bacterial Populations

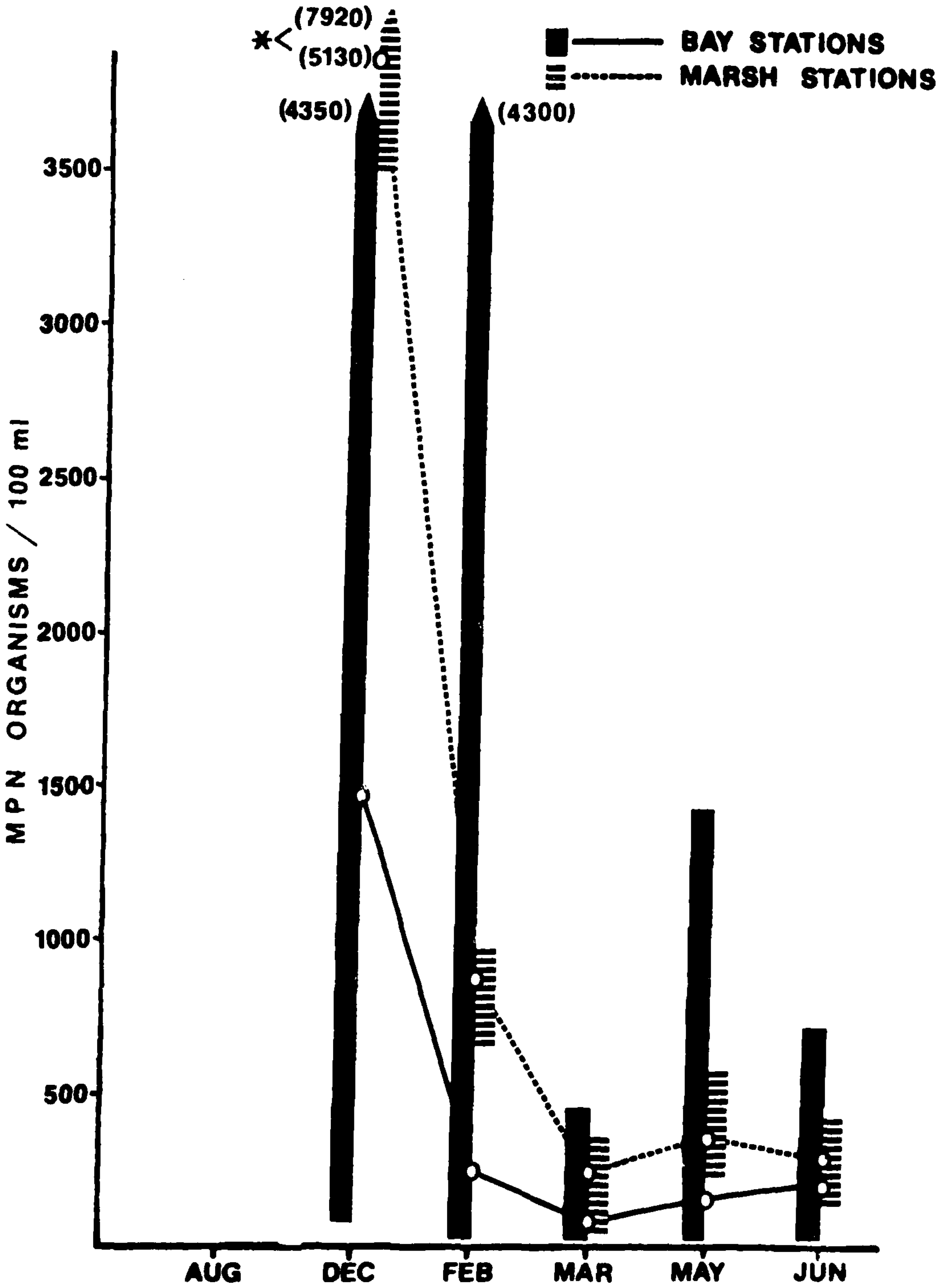
The most probable number (MPN) of coliform bacteria were counted from all bottom water samples and the resulting numbers shown on Figure 17. The very high counts, above 4500 organisms for December, are possibly biased by the technique used which allowed the plate with the organisms to dry out before or during counting. The drying out process altered the color of the colonies and may have allowed the counting of non-coliform colonies. The apparatus for coliform counts was changed and the problem eliminated for all subsequent samples. Discounting those high counts of December, we still encountered a range of values of from less than 10 to 4,310 coliform organisms. Coliform bacteria are used as an indicator of the degree of pollution that might occur because of sewage or animal wastes. The data in Figure 17 shows that for all months the marsh samples had higher coliform counts than those from the bay. This may reflect in part the extensive inhabitation of the marshes by nutria and cattle, or it may reflect the fact that the marshes filter much of the river water before it enters the bay. After December and February, which had the highest counts of the study period, the coliform counts for the remainder of the investigation stayed fairly constant. The Texas State Department of Health recorded MPN coliform counts in Trinity Bay through 1970, 1971, and 1972 that had a mean value of 72 coliforms/100 ml (Travis, 1972).

The total bacterial counts for bottom water samples in the bay and mid-depth in the marshes are shown on Figure 18. The counts appear to be uniform with a slight trend towards an increase throughout the study period. This is in contrast to most of the parameters observed, which tend to decrease, probably as a result of dilution. Most of the observed microbial populations were on the order of 10^6 organisms per milliliter of water. The total counts ranged from $8x10^4$ to $9x10^6$ in the bay samples but a much smaller range of values was observed in the marshes. Note that many of the mean values are near one end of the range of values for many sampling periods. This indicates that the extreme counts were few in number.

The total counts of bacteria from bay and marsh sediments are shown on Figure 19. In August 1972, the total bacterial populations observed were around 10^9 cells/ml. The bacterial populations increased in December to around $3x10^{10}$ and then gradually decreased in each subsequent sampling period. The total counts for both bay and marsh sediments appeared to be very similar to one another, but with the marsh sediments always having lower mean count than the bay sediments.

Counts similar to those observed here have been made for the marine environments in Puget Sound, Washington, using the same techniques. The Puget Sound counts totaled $1x10^3$ to $1x10^9$ cells/ml (Watson, Smith, Ehrsam, Parker, Blanton, Solomon, and Blanton, 1971). Similar counts ($4x10^5$ to $8.6x10^7$ cells/ml) were obtained in two south Texas bays after Hurricane Beulah (Berry, 1969). Somewhat lower counts (0 to $1x10^6$ cells/ml) were made on sediments from the Brazos and Colorado estuaries by

Figure 17. Coliform bacteria counts per 100 ml of bottom water for sampling periods August 1972-June 1973 within Trinity Bay and delta marshes.



(7920)
*<
(5130)
(4350)
(4300)
BAY STATIONS
MARSH STATIONS
3500
3000
2500
2000
1500
1000
500
MPN ORGANISMS / 100 ml
AUG
DEC
FEB
MAR
MAY
JUN

* See text

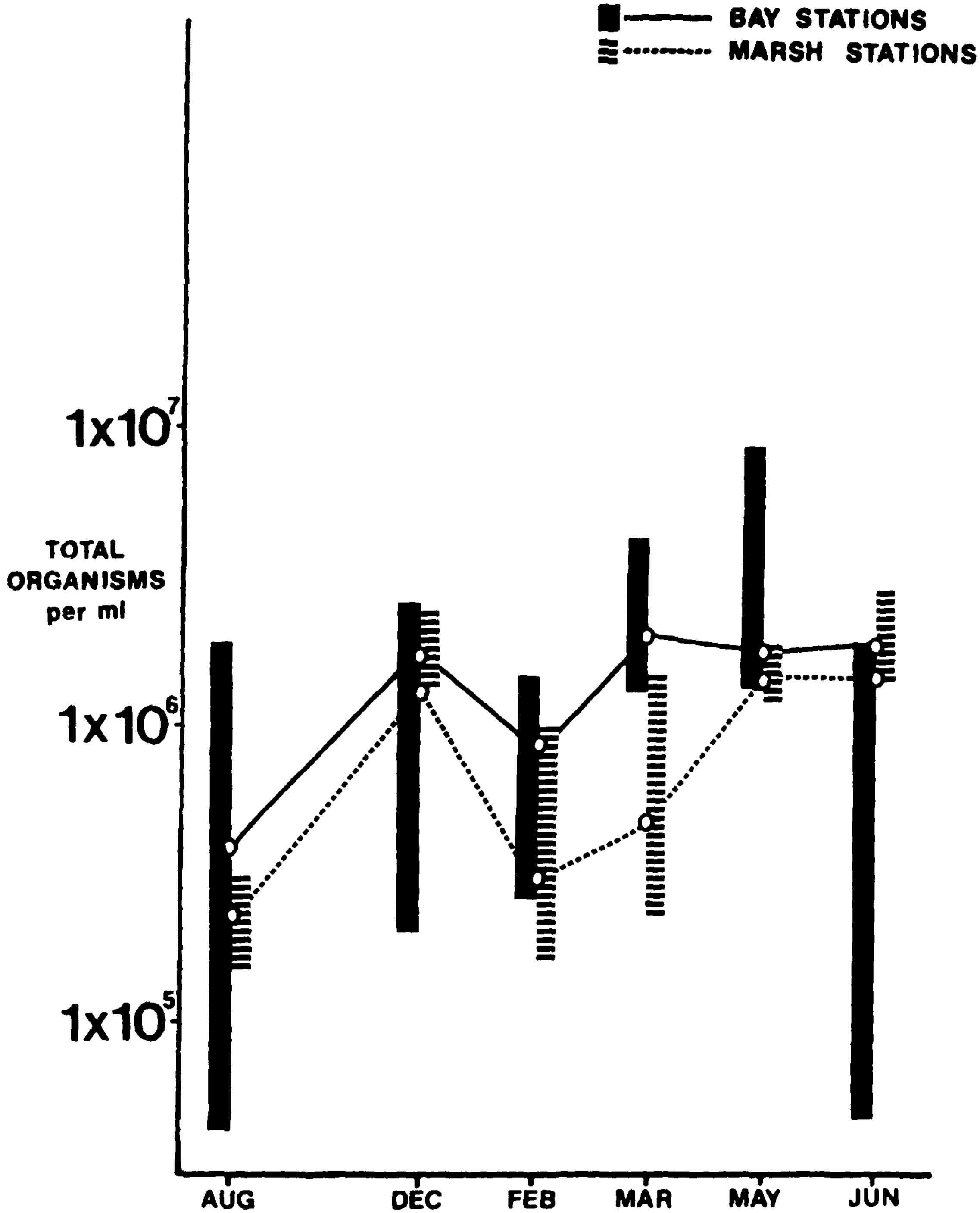


Figure 18. Total bacterial counts in bottom water samples for sampling periods August 1972-June 1973 within Trinity Bay and delta marshes.

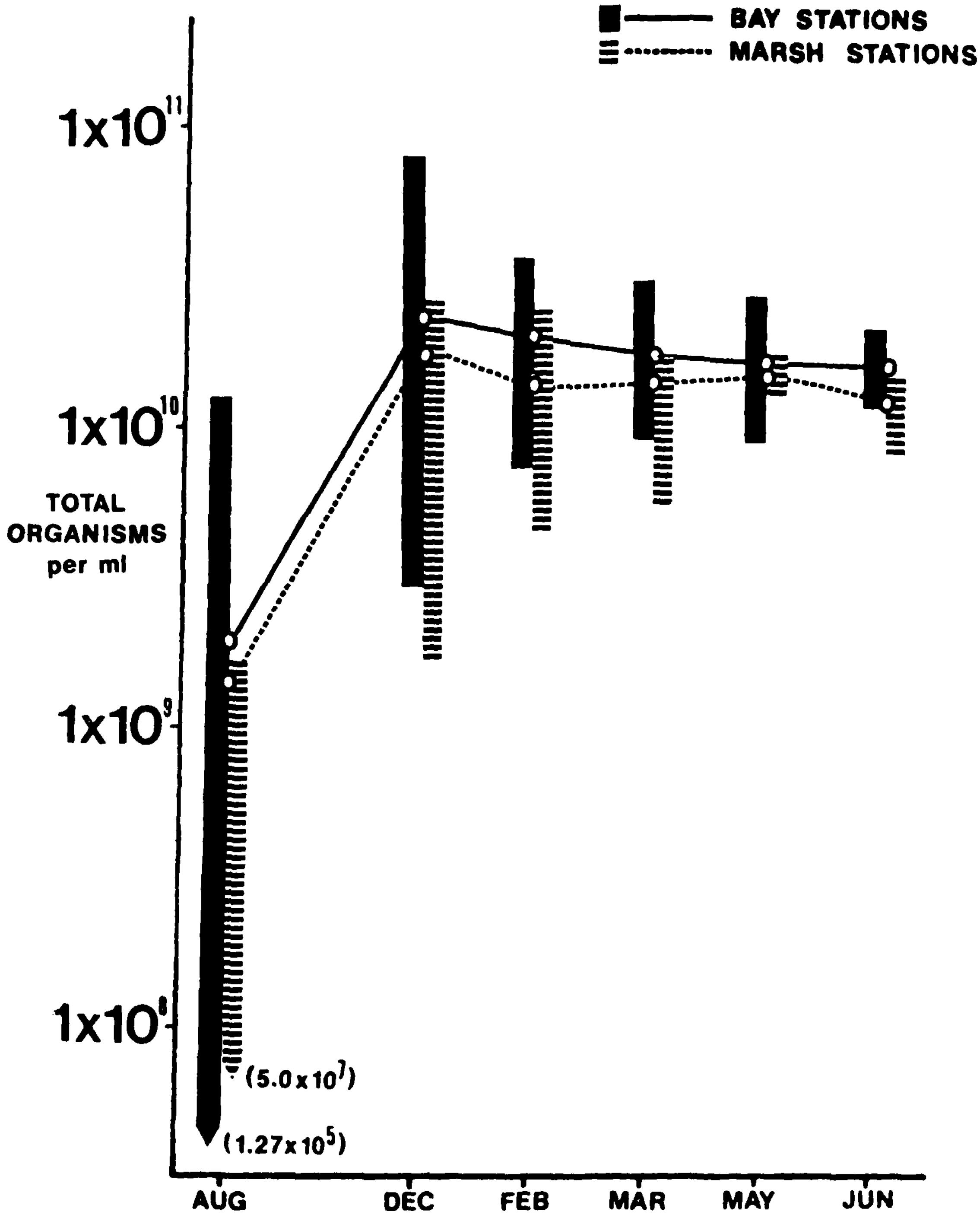


Figure 19. Total bacterial counts in sediment samples for sampling periods August 1972-June 1973 within Trinity Bay and delta marshes.

Parker, *et al.* (1969) and in Cedar Bayou by Culpepper, *et al.* (1969). The latter three sets of counts were made by direct count and plating only and may not be strictly comparable to the Puget Sound and Trinity Bay counts. These very high bacterial populations represent what we believe to be the major trophic level in the Trinity Bay ecosystem. According to various textbooks on microbial ecology, populations over $1x10^6$ cells/ml exert considerable control over the ecosystem.

Plankton Populations--Chlorophyll-a Production

Plankton samples were obtained at selected stations in the bay on each sampling trip. Simultaneous collections of water were made for measurements of the production of chlorophyll-a. The results of the comparisons of these samples are shown on Figure 20, while a list of phytoplankton genera observed can be found in Table 1. It is immediately apparent that there was no correlation between the size of the phytoplankton community and the production of chlorophyll-a. The phytoplankton populations reached their minimum in December when chlorophyll production was greatest, and the maximum plankton populations appeared in February when one of the two minima of chlorophyll production was observed. This relationship is awkward because Graham (1943) established that a fair correlation should exist between the quantity of chlorophyll produced and the phytoplankton mass.

The plankton counts are very low and reflect in part the very low populations that usually occur in estuaries with heavy inflows of fresh water, and in part the method of sampling. The net used in this study collects only those planktonic forms larger than 60 microns which is

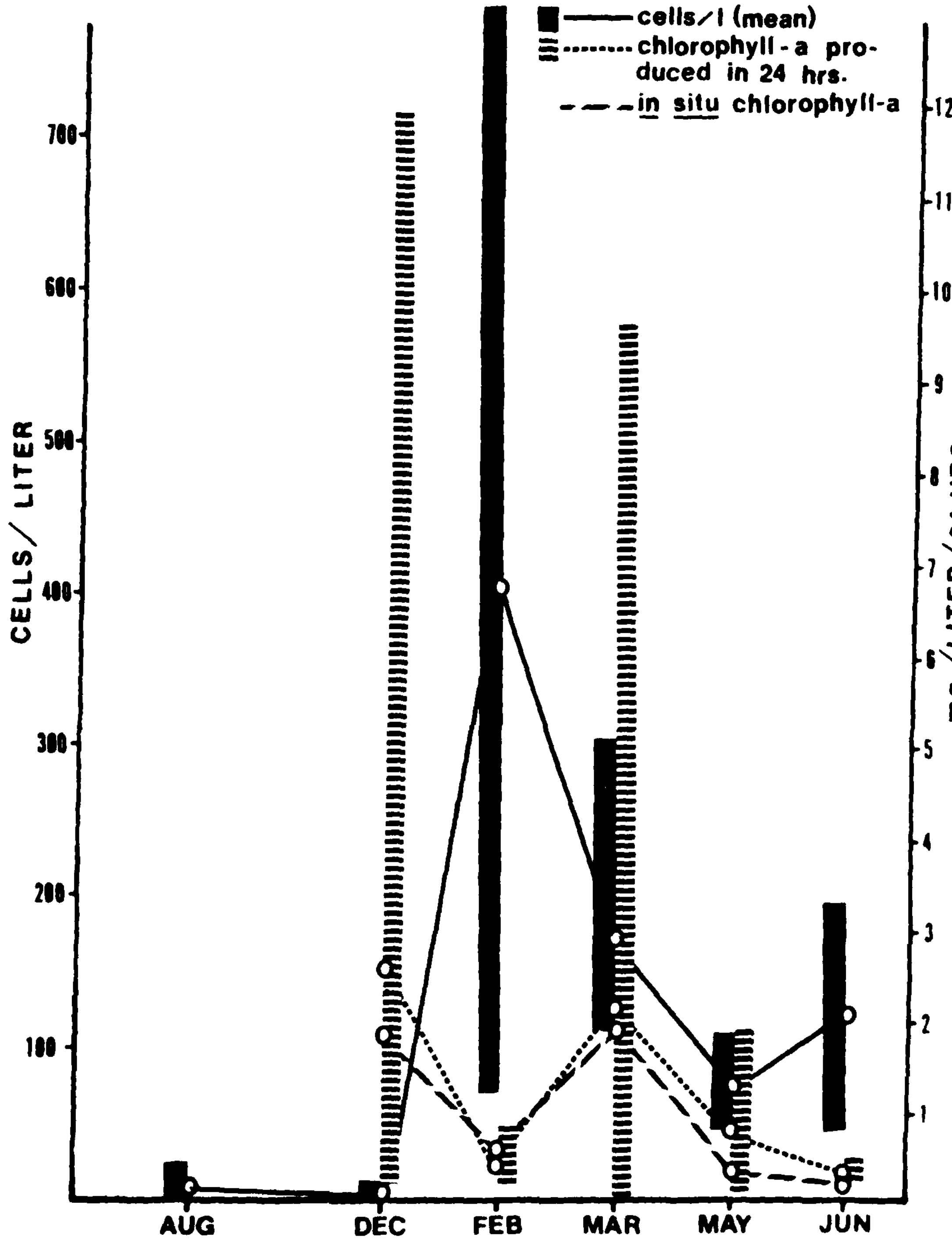


Figure 20. Phytoplankton cell counts/liter compared with chlorophyll-a *in situ* values and 24 hour production values from samples taken between August 1972-June 1973, within Trinity Bay.

TABLE 1

PHYTOPLANKTON GENERA COLLECTED IN TRINITY BAY
AUGUST 1972 - JUNE 1973

Cyanophyta:
Anabaena sp.

Chrysophyta: Bacillariaceae (Diatoms)
Asterionella spp.
Biddulphia spp.
Coscinodiscus spp.
Ditylum spp.
Guinardia spp.
Hemiaulus spp.
Leptocylindricus spp.
Lithodesmium spp.
Navicula spp.
Nitzschia spp.
Pleurosigma (Gyrosigma) spp.
(two combined by Wood, 1963)
Rhizosolenia spp.
Skeletonema spp.
Surirella spp.
Thalassiothrix spp.

Chlorophyta: (Green algae)
Closterium spp.

Protozoa: Mastigophora: Dinoflagellata
Ceratium spp.
Gymnodinium spp.

Rotifera:
Keratella sp.
Pompholyx sp.

considered microplankton and only represents approximately 10 percent of the total plankton (Martek Mariner, 1969). A number 25 mesh does not collect the nannoplankton (5-60 microns) or the ultraplankton (<5 microns). If a known volume of water is collected without a net and centrifuged or filtered for the organisms present, it is to be expected that the total populations reported will be much higher than if only a number 25 mesh net is used for filtration. Parker and Blanton (1970) cite 21,000-51,000 cells/liter in Corpus Christi Bay and 303,000 cells/liter in Redfish Bay from samples collected by filtration. Smith, Williams, and Davis (1950) cite plankton populations of <0.5-22.9 milliliter of plankton filtered from a "standard sample" taken with a net off Florida. Copeland and Fruh (1970) reported populations from Trinity Bay samples of from 22 to 109 cells per milliliter. However, by using their total population counts cited in their appendix (appendix, Table 23, pages 440-442) and dividing them by the number of liters in two cubic meters of water (the amount of water filtered by their net), their data yield populations of only 0.1-9.5 cells per liter.

The populations in Trinity Bay observed in this study would still be low even if they were considered to represent only 10 percent of the phytoplankton. The trends in the population from season to season were at some variance to the "normal". Plankton populations usually exhibit a spring maximum each year in March or April and a minimum in late summer or early fall. However, Smith, *et al.* (1950) showed that in the subtropical waters off Miami the total net volumes exhibit two maxima, one in December-January, and one midsummer. The high phytoplankton population observed in February could correspond with the winter maxima of Smith, *et al.* (with a different climatic regime) which is surprising, considering that water temperatures were still quite low in February. The small populations in May were probably due, in a large part, to an extremely large zooplankton population. We did not treat the zooplankton quantitatively in this investigation; however, in May some plankton samples were approximately 90 percent zooplankton and 10 percent phytoplankton, with copepods (primary grazers) dominating the zooplankton. In addition, it should be noted that in March, May, and June there were many rotifers in the plankton samples and rotifers are predominantly fresh-water organisms probably supported by flood waters.

The production of chlorophyll-a was very irregular from sampling period to sampling period. Production also was extremely varied throughout the area during any one sampling period as is evidenced by the wide range of values observed in December and March. There appeared to be a general decreasing trend in chlorophyll-a production except for the month of March. This may only be evidence of the dilution effect of the Trinity flood waters. Marshall (1956) cited chlorophyll-a measurements in Alligator Harbor, Florida, of 1-12 mg/m^3 as *in situ* measurements. Davis (1971) cited *in situ* measurements of chlorophyll-a in San Antonio Bay of 2-86 mg/m^3 during the course of a year. However, Davis (1971) did not give population sizes, while Marshall (1956) cited populations of 1-15 million cells per liter. The chlorophyll-a measurements in Trinity Bay were in the same range (0.1-11.3 mg/m^3) but occurred when the plankton population never exceeded 800 cells per liter. Marshall (1956) also performed productivity experiments which mostly yielded declines in chlorophyll content but also showed a range of production of 0.2-1.4 mg/m^3 per 24 hours. Chlorophyll production in Trinity Bay samples ranged from a mean decrease in February to mean production values of 0.74-2.53 mg/m^3 per 24 hours.

Marsh Vegetation

The standing crop in dry weight of vegetation clipped at the quadrat stations in the marshes is shown on Figure 21. Table 2 is a list of selected species and their abundance at our station locations in the marsh. Stations 25 and 26, taken in the delta, were dominated almost exclusively by alligator-weed (*Alternanthera philoxeroides*). Station 27 was characterized by saltgrass (*Distichlis spicata spicata*) during the fall and winter, but was underwater during the sampling periods in May and June, at which time it was dominated by alligator-weed. Figure 21 for stations 25, 26, and 27 in the month of May represent extrapolations taken from the amount of vegetation clipped down to the surface of the water, then extrapolated to include the vegetation between the surface of the water and the surface of the sediments. Stations 29 and 30 were areas of cattle pasturing and were dominated by the cordgrasses (*Spartina* spp.). Extensive collections of species were not made since effort was expended only in securing the clipped quadrats. The large drop in biomass from December to February was attributed to the physical removal of much of the standing vegetation from the marshes by the first surges of high flood waters. The additional decreases from February to March were probably due to low temperatures and low photosynthetic levels, typical of winter. The delta stations, from March to May, were characterized by remarkable growth of alligator-weed which attained heights

TABLE 2

ABUNDANCE AND DISTRIBUTION OF SELECTED MARSH PLANTS

Species	Stations[1]							
	25	26	27	28	29	30	51	52
Amaranthaceae								
Alternanthera philoxeroides Alligator-weed	D,A	D,A	D*,A	F				
Bataceae								
Batis maritima Saltwort	I	I				I		I
Chenopodiaceae								
Salicornia sp. Glasswort	I	I				I		I
Suaeda sp. Seepweed	I	I						
Compositae								
Solidago sempervirens Seaside goldenrod	A	A						
Borrichia frutescens Sea ox-eye daisy	F	F						
Cyperaceae								
Scirpus robustus Bulrush	I	I					F	
Gramineae								
Distichlis spicata spicata Saltgrass			D*,A	D,A	I	A		A
Phragmites communis Common reed	I	I			A		A	

TABLE 2 (continued)

Species	Stations[1] 25	26	27	28	29	30	51	52
Gramineae (continued)								
Spartina spartinae Coastal sacahuista					I	I		
S. alterniflora Smooth cordgrass						A		A
S. cynosuroides Big cordgrass					I		I	
S. patens Saltmeadow cordgrass			F		D,A			
Juncaceae								
Juncus sp. Rush	F	F	F		F		A	
Ruppiaceae								
Ruppia maritima Widgeon-grass						I		

Symbols: D -dominant; I -infrequent; F -frequent; A -abundant
*Dominant only during part of the year

[1]Stations 25, 26, 27, 28, and 51 have predominantly fresh to low salinity waters
Stations 29, 30, and 52 have fresh to medium salinity waters.

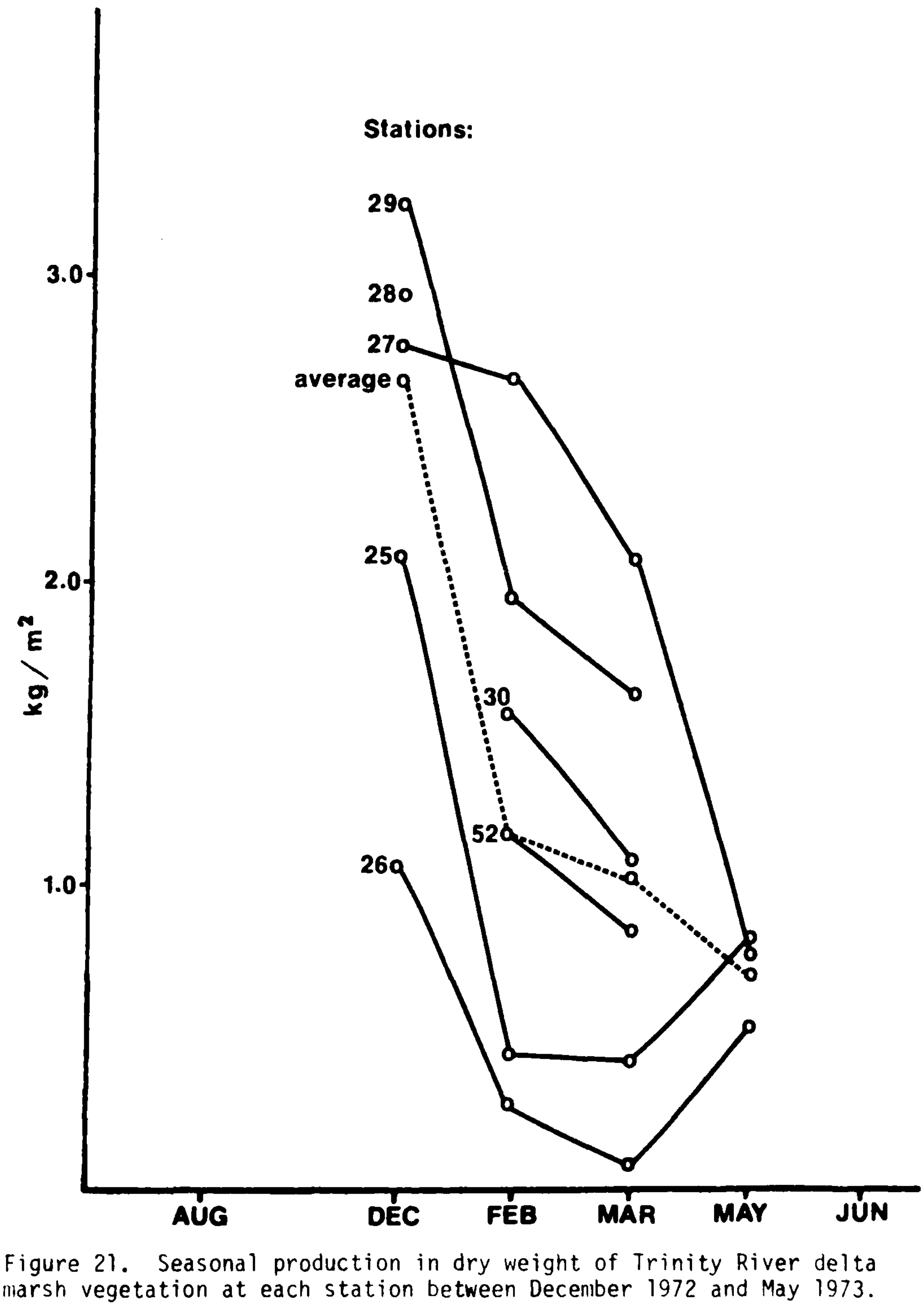


Figure 21. Seasonal production in dry weight of Trinity River delta marsh vegetation at each station between December 1972 and May 1973.

of over a meter in the six weeks period. Station 27 continued to have decreased amounts of vegetation after the May sampling but not because of reduced growth of the alligator-weed, but rather that the alligator-weed was more succulent than at other stations and thus the dry weight was a very small percentage of the sample weight.

Benthic Invertebrates--Diversity Indices

The numbers and diversity of benthonic organisms are highly indicative of the condition of an estuary at any point in time (Davis, 1971). The mean numbers of benthos and the diversity indices for the C.E.M. sampling periods are shown on Figure 22. The widest range of numbers of benthos with the highest maximum number observed in the study occurred during August 1972. The samplings in December, February, March, and May had very similar ranges in the numbers of benthic organisms taken, while June showed a reduced range. The mean number of benthic individuals decreased from August to December 1972, but remained fairly stable from February through June. It is interesting to note that the diversity indices for all months remained within one tenth of a unit of each other. The plot of the mean diversity indices (DI) for August, December, February, May, and June closely approach that of a straight line. The graph of the mean number of invertebrates is located nearer the minimum end of the range of values rather than the maximum, and this is a result of there always being a few stations with large populations while the majority of stations have populations closer to the mean. Davis (1971) observed that invertebrates in San Antonio Bay numbered from 4 to 494 per $foot^3$. The numbers of

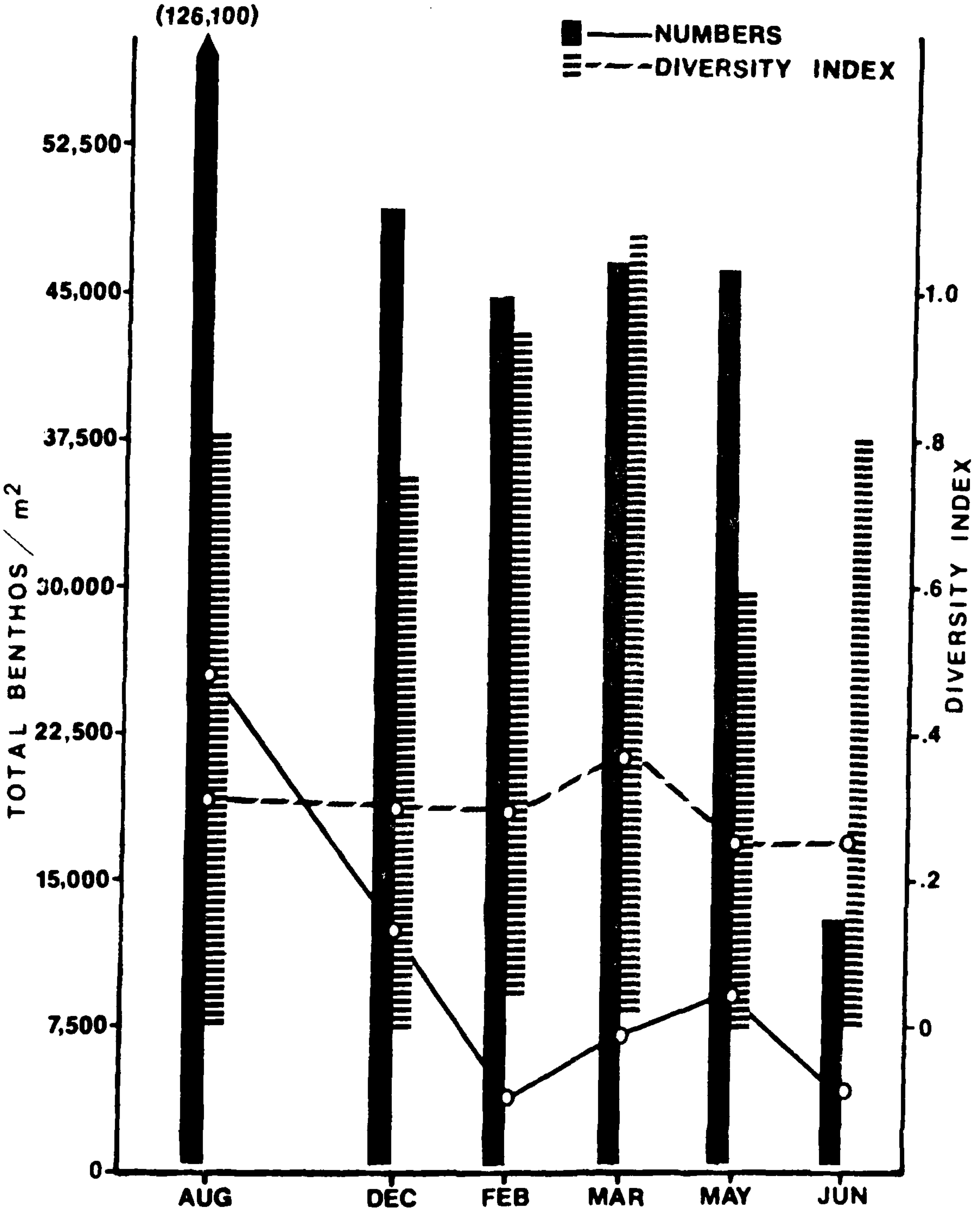


Figure 22. Mean and extremes of bottom invertebrate counts from 1/25 m^2 Van Veen grab samples compared with calculated Shannon-Weaver diversity indices within Trinity Bay between August 1972 and June 1973.

invertebrates taken in this study, if converted to numbers per $foot^3$, would range from 69 to 419 per $foot^3$. These same numbers (4,158 to $25,155/m^2$) from Trinity Bay in 1973 are much higher than those from Trinity Bay in 1969, when Copeland and Fruh (1970) cited numbers of from 1,000 to $7,100/m^2$. On the other hand, those investigators used a number 30 mesh sieve (595 micron opening) and thus captured fewer organisms per unit sample than we did, using a number 60 mesh sieve (250 micron opening).

The same diversity index was used in this study as was used by Copeland and Fruh (1970); *i.e.*, the modified Shannon Weaver index. The diversity indices in 1972-73 in Trinity Bay ranged from 0.01 to 1.08, while the Trinity Bay stations of Copeland and Fruh (1970) ranged from 0 to 1.48. While the range of values of the indices are similar in both investigations, the quarterly means in 1969 (Copeland and Fruh, 1970) were much higher (0.44-0.86) than the monthly means in 1972-73 (0.27-0.40). The significant point to be made of these data is that the trend of the diversity index in both of these studies was very similar. The diversity index was stable through the fall and winter, reaching a maximum in March and then decreased through the spring into a minimum im midsummer.

Nekton-Epibenthos

The numbers and kinds of fish and invertebrates that were trawled in the bay or seined from the marshes are shown in Table 3 and the median catches per unit effort are graphed on Figure 23. No trawl or seine catches were taken in August 1972 or June 1973 and no seines were attempted in the marshes in December 1972. Table 3 indicates that catch effort and success were too low for any significant statistical analyses. Even the mean catch per effort data are influenced by the small number of samples with wide ranges of values. The primary significance of data in Figure 23 and Table 3 is that they indicate when organisms were present in the bay and in the marshes. The trawl captured fish in numbers ranging from 0 to 316. Other investigators in Trinity Bay used trawls with smaller meshes and captured much greater numbers. Baldauf, *et al.* (1970) used a trawl with a cod end mesh of 16 mm (1/16 inch) and recorded captures of 1 to 7800 fish per trawl. Copeland and Fruh (1970) used a trawl with a cod end mesh of 63 mm (1/4 inch) and captured from 1 to 2100 fish. Baldauf, *et al.* (1970) also seined with a 16 mm mesh and captured far greater numbers than recorded for this study. In that our equipment and technique yielded captures each month, information on year classes and presence or absence of the important commercial species was obtained. Additional information on productivity in the bay (unpublished data, 1973) was provided by Mr. Robert Hofstetter of the Texas Parks and Wildlife Department, in the form of total oyster production for the Galveston Bay System (Table 4).

Sediment Composition

Sediment composition exerts a considerable control on the distribution of bottom-living animals. The distribution of sediments has a direct relationship to circulation and any changes in circulation occurring as a result of management changes in river discharge. The sediment composition at the various stations as defined by their percentages of sand, silt, and clay are shown on Figures 24, 25, 26, and 27. The sediment

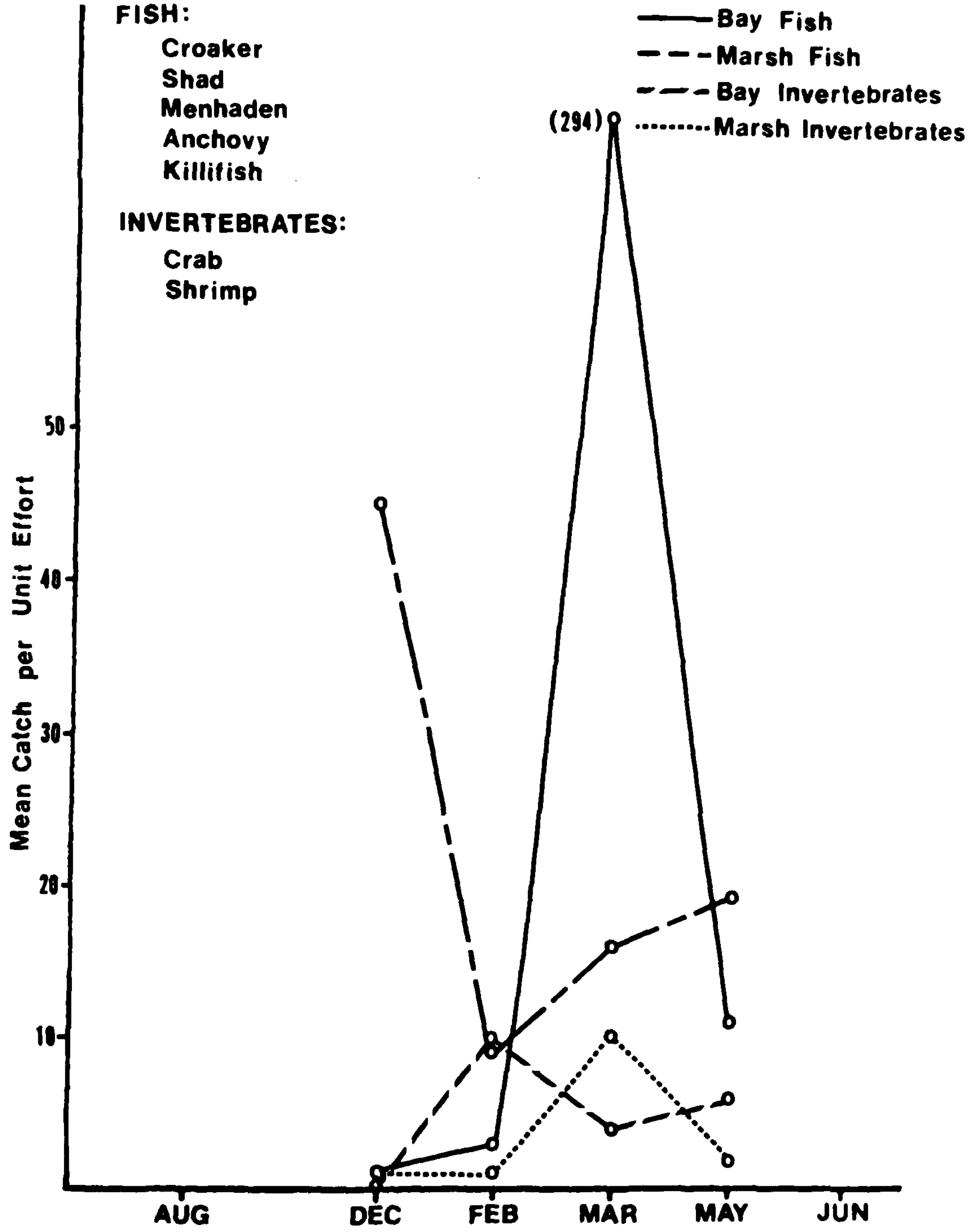


Figure 23. Mean catch per unit effort for fish and invertebrates, Trinity Bay and marshes, December 1972-May 1973.

TABLE 3

NEKTONIC AND EPIBENTHIC ORGANISMS COLLECTED IN TRINITY BAY AND ADJACENT MARSHES

Stations	Sampling Device	Species	Number of Specimens	Sizes
		DECEMBER		
34	Trawl	Jellyfish	1	10 mm (diameter)
		Callinectes sapidus Blue crab	1	14 mm (carapace width)
		Micropogon undulatus Croakers--juvenile	10	15-30 mm
		Mugil cephalus Striped mullet	1	100 mm
		Dorosoma petenense Threadfin shad	5	3 = 32 mm 1 = 52 mm 1 = 80 mm
		Brevoortia patronus Gulf menhaden	120	10 = 57-88 mm 110 = 19-46 mm
32	Trawl	*Ictalurus punctatus* Channel catfish	2	70 mm and 274 mm
		FEBRUARY		
1	Trawl	*Micropogon undulatus* Atlantic croaker	1	58 mm
		Jellyfish	26	35-60 mm (diameter)
		Comb jelly	1	...
		Anchoa mitchilli Bay anchovy	7	32-38 mm
7	Trawl	*Micropogon undulatus* Atlantic croaker	1	55 mm

TABLE 3 (continued)

Sta- tions	Sampling Device	Species	Number of Specimens	Sizes
8	Trawl	*Callinectes sapidus* Blue crab	3	1 = 98 mm 1 = 63 mm 1 = 94 mm
		Micropogon undulatus Atlantic croaker	1	28 mm
		Brevoortia patronus Gulf menhaden	1	84 mm
25	Seine	*Dorosoma petenense* Threadfin shad	1	77 mm
27	Seine	*Fundulus similis* Longnose killifish	1	80 mm
		Fundulus grandis Gulf killifish	2	39-41 mm
		Callinectes sapidus Blue crab	2	16-35 mm
		Penaeus aztecus Brown shrimp	1	...
		Dorosoma petenense Threadfin shad	36	28-32 mm
	Cast net	*Micropogon undulatus* Atlantic croaker	5	52-54 mm
		Syngnathus scovelli Gulf pipefish	1	185 mm
36	Trawl	*Callinectes sapidus* Blue crab	25	16-161 mm
		Micropogon undulatus Atlantic croaker	17	21-156 mm
		Dorosoma petenense Threadfin shad	1	31 mm
46	Trawl	*Micropogon undulatus* Atlantic croaker	5	3 = 28-42 mm 2 = 130-158 mm
		Callinectes sapidus Blue crab	1	44 mm

TABLE 3 (continued)

Stations	Sampling Device	Species	Number of Specimens	Sizes
		Anchoa mitchilli Bay anchovy	1	28 mm
		Brevoortia patronus Gulf menhaden	1	45 mm
		Comb jelly	1	4 mm (diameter)
		MARCH		
25	Seine	*Micropogon undulatus* Atlantic croaker	2	25-76 mm
		Fundulus similis Longnose killifish	67	36-40 mm
		Fundulus grandis Gulf killifish	15	38-76 mm
30a	Seine	*Callinectes sapidus* Blue crab	13	1 = 13 mm 5 = 24-26 mm 6 = 60-61 mm 1 = 102 mm
		Micropogon undulatus Atlantic croaker	16	8 = 25-51 mm 8 = 51-76 mm
		Anchoa mitchilli Bay anchovy	4	38-40 mm
		Brevoortia patronus Gulf menhaden	1	25.4 mm
30b	Seine	*Callinectes sapidus* Blue crab	24	17 = 6-13 mm 4 = 25-32 mm 3 - 38-51 mm
		Penaeus aztecus Brown shrimp	1	13 mm
		Anchoa mitchilli Bay anchovy	10	25-38 mm
		Fundulus grandis Gulf killifish	1	76.2 mm
		Micropogon undulatus Atlantic croaker	18	14 = 25-51 mm 4 = 51-76 mm

TABLE 3 (continued)

Stations	Sampling Device	Species	Number of Specimens	Sizes
36	Trawl	*Micropogon undulatus* Atlantic croaker	273	251 = 19-76 mm 21 = 76-127 mm 1 = 178 mm
		Penaeus aztecus Brown shrimp	3	101-103 mm
		Callinectes sapidus Blue crab	9	6 = 37-39 mm 1 = 127 mm 2 = 151-153 mm
46	Trawl	*Micropogon undulatus* Atlantic croaker	315	298 = 19-76 mm 15 = 76-127 mm 2 = 164-166 mm
		Callinectes sapidus Blue crab	2	50-52 mm
		Arius felis Sea catfish	1	267 mm
		MAY		
1	Trawl	*Micropogon undulatus* Atlantic croaker	11	1 = 60 mm 1 = 70 mm 7 = 79-81 mm 1 = 110 mm 1 = 135 mm
		Callinectes sapidus Blue crab	1	32 mm
25	Seine	*Mugil cephalus* Striped mullet	2	65-80 mm
		Leiostomus xanthurus Spot	1	71 mm
		Brevoortia patronus Gulf menhaden	14	28-49 mm
27	Seine	*Dorosoma cepedianum* Gizzard shad	7	80-91 mm
		Brevoortia patronus Gulf menhaden	11	3 = 36-49 mm 8 = 61-65 mm
		Leiostomus xanthurus Spot	1	71 mm

TABLE 3 (continued)

Stations	Sampling Device	Species	Number of Specimens	Sizes
30	Seine	*Brevoortia patronus* Gulf menhaden	121	33-54 mm
		Micropogon undulatus Atlantic croaker	3	78-93 mm
		Callinectes sapidus Blue crab	3	18-28 mm
		Penaeus aztecus Brown shrimp	1	35 mm (tip to tip)
		Dorosoma cepedianum Gizzard shad	3	70-79 mm
34	Trawl	*Callinectes sapidus* Blue crab	11	33-72 mm
		Brevoortia patronus Gulf menhaden	1	51 mm
		Leiostomus xanthurus Spot	4	39-60 mm
		Micropogon undulatus Atlantic croaker	74	1 = 129 mm 5 = 29-33 mm 1 = 91 mm 67 = 33-79 mm
36	Trawl	*Micropogon undulatus* Atlantic croaker	1	47 mm
42	Trawl	0	0	0
46	Trawl	*Micropogon undulatus* Atlantic croaker	3	1 = 43 mm 1 = 100 mm 1 = 86 mm
		Mugil cephalus Striped mullet	1	31.75 cm

TABLE 4

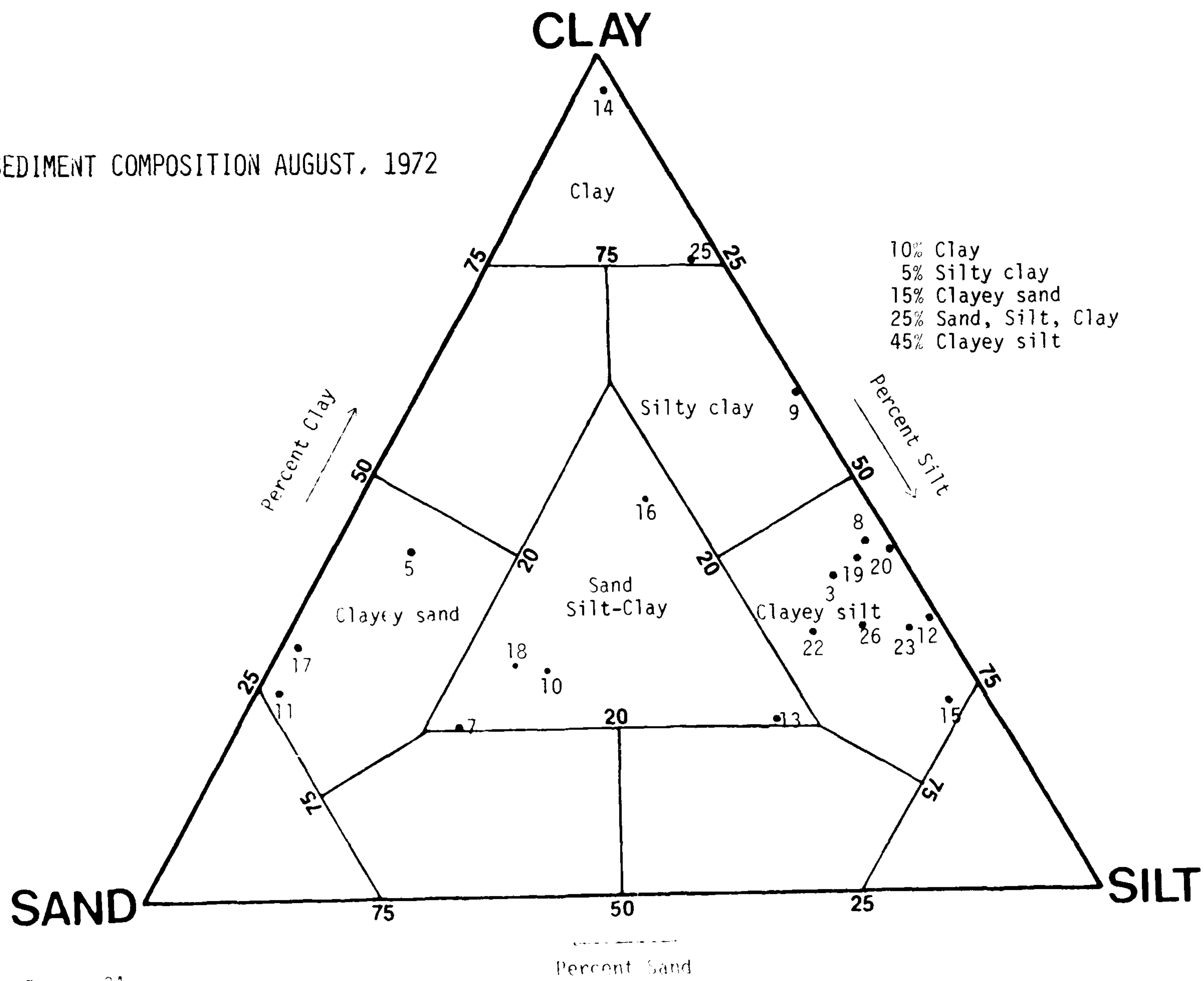
OYSTER PRODUCTION IN GALVESTON BAY 1972-73

Month	Days Open	Pounds of Meat	Value
November 1972	30	1,057,437	$640,128
December 1972	31	738,906	452,738
January 1973	31	552,297	338,598
February 1973	28	420,737	261,461
March 1973	24*	237,858	145,093
April 1973	16*	61,215	36,729

*Entire bay closed March 24, 1973; East and West Bays opened April 7, 1973; bay proper opened April 14, 1973

Figures 24-27. Sediment composition at various stations, for sampling periods August 1972-June 1973, plotted as percentages of sand, silt, and clay, derived from mechanical analysis, Trinity Bay, Texas.

SEDIMENT COMPOSITION AUGUST, 1972



10% Clay
5% Silty clay
15% Clayey sand
25% Sand, Silt, Clay
45% Clayey silt

Figure 24

SEDIMENT COMPOSITION DECEMBER, 1972

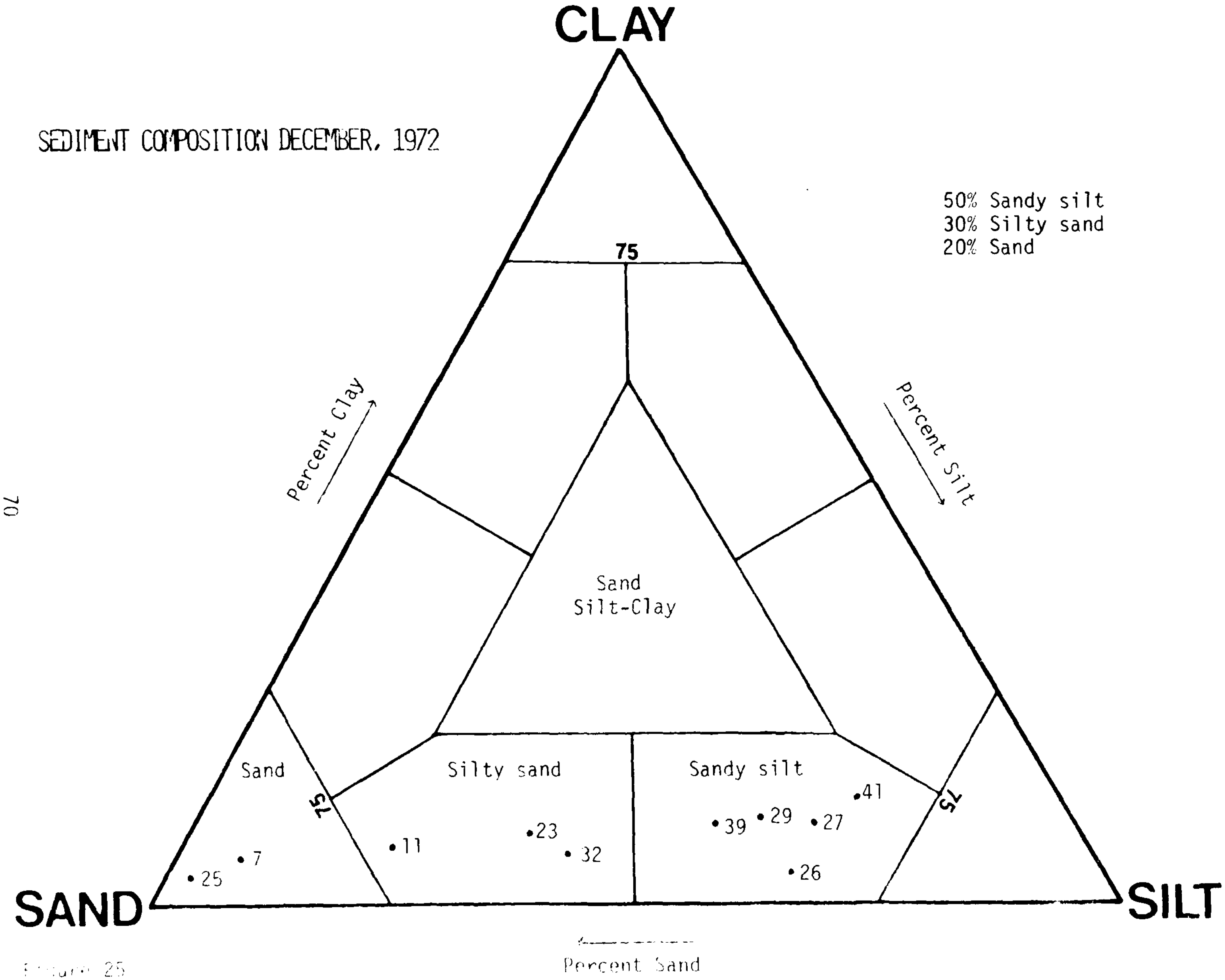


Figure 25

SEDIMENT COMPOSITION FEBRUARY, 1973

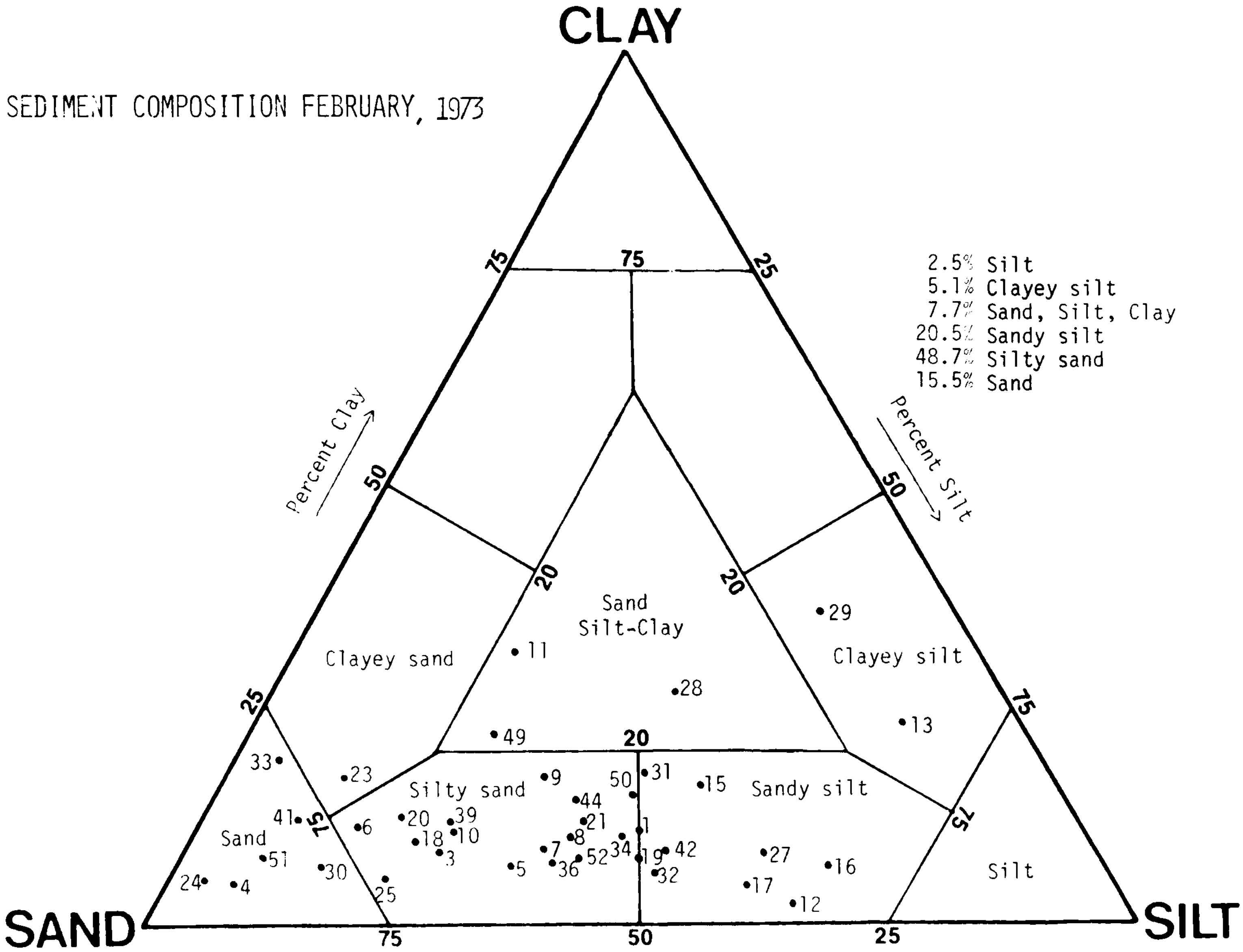


Figure 26

SEDIMENT COMPOSITION JUNE, 1973

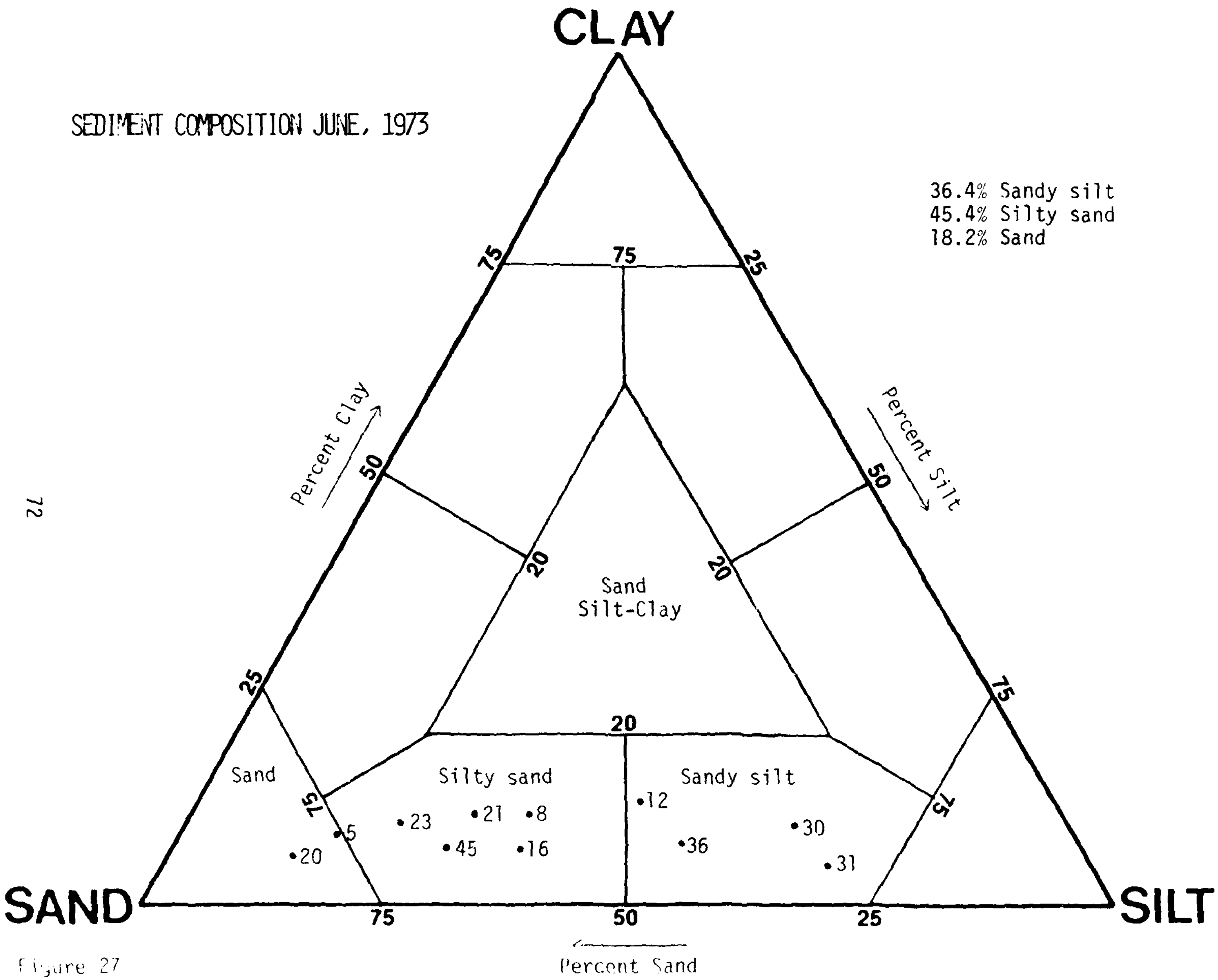


Figure 27

composition trends for the entire study period are shown graphically on Figure 28. The three-dimensional triangular diagrams show the changing composition of individual stations, some of which are very dramatic, while the composite graph of sand, silt, and clay percents (Fig. 28) shows how all sediments changed through the study period. Except for December, the percentage of silt remained within a range of variation of one or two percent. With the greatly increased river flow during the study period, it could be expected that the finest particles (clay) would be flushed from the bay. Parker, *et al.* (1969) observed a direct relationship between river discharge and sediment composition at certain locations in the Brazos and Colorado Rivers, but flow rates in river estuaries are much greater than in the bay type estuary. Those authors did correlate high flows with high sand percentages at several river locations, and high silt percentages with low flow conditions. Renfro (1959a) characterized all of Trinity Bay sediments as mud-shell with live oyster reefs in the areas near Smith Point, Cedar Point, and Umbrella Point. An areal description of sediment types for Trinity Bay is given in Parker, *et al.* (1972). That gross pattern changed little over the period of study.

DISCUSSION

The objectives of this report are to provide answers to questions such as: How does the discharge of the Trinity River affect the water quality in Trinity Bay? What would reduced flow of the Trinity River do to the biological communities in Trinity Bay? Is the Trinity River important in providing nutrients to Trinity Bay? What role do the marshes play in

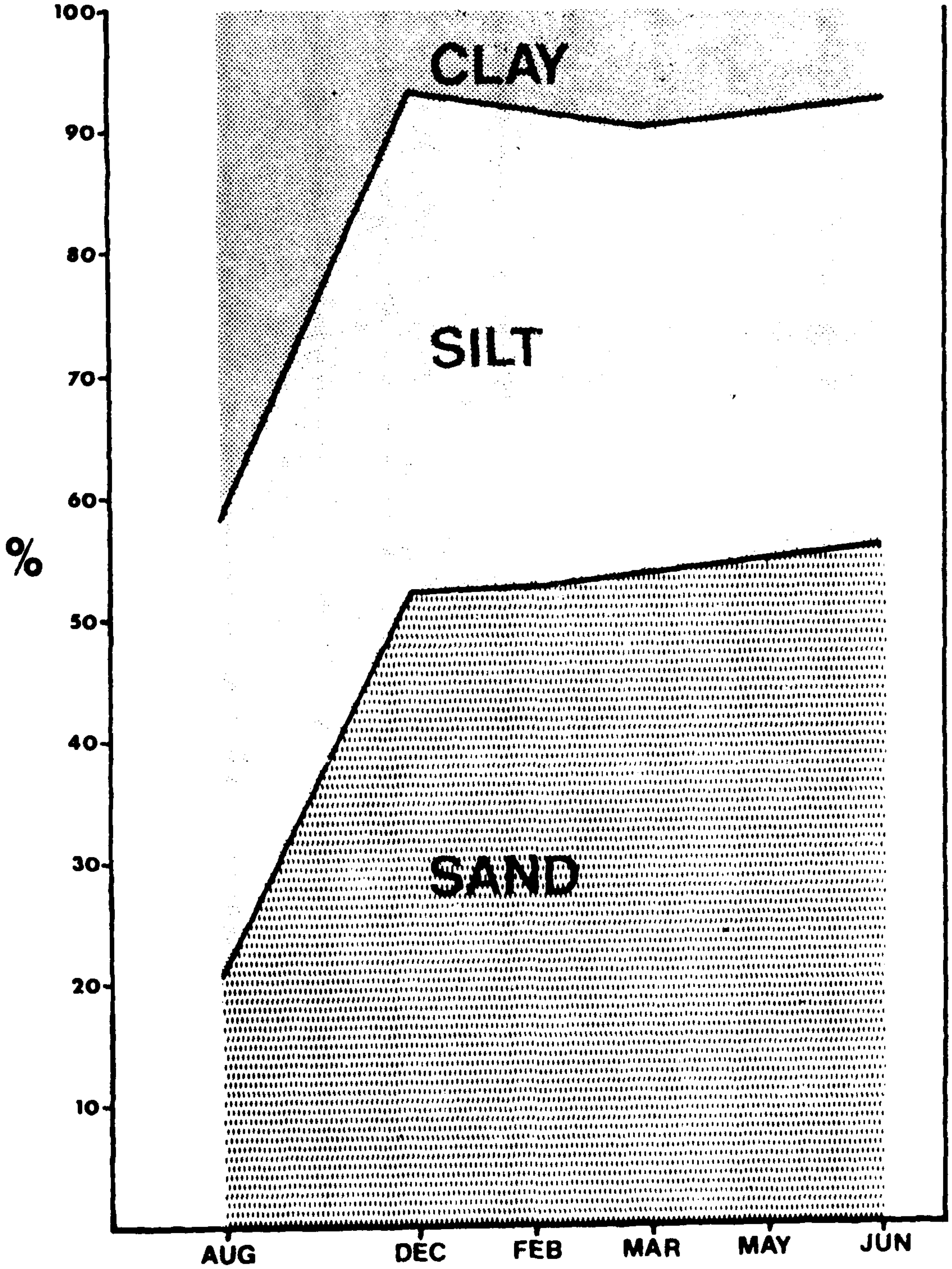


Figure 28. Gross mean sediment compositional change for Trinity Bay bottom sediments, August 1972-June 1973.

the estuarine ecosystem?

Certain guidelines are already present in the form of general ecological principles governing estuarine ecosystems. A reduction in river flow into a river fed bay-type estuary will raise the salinity, will vary the circulation patterns, will reduce the water level of the marshes, will reduce silting and deposition rates, and will reduce the amounts of nutrients (Diener, 1964). Each of these phenomena can have an effect on productivity. In the case of a salt water barrier in the Trinity estuary, Steed (1971) believes the marshes above the barrier would be lost to flooding, the marshes below the barrier will be damaged through the loss of fresh water and reduced nutrients for portions of each year.

The most important questions needing answers before management decisions affecting the flow of the Trinity should be made are those questions concerning the effects of low river flow. The concern for the effects of low flow on productivity stem from the fact that many of the management decisions concerning river flow are directed towards impoundments or diversions or use permits that usually serve to reduce the overall discharge rate to the estuary. Ultimately, the minimum flow that the estuary needs to sustain a proper level of productivity will have to be determined.

The flow of the Trinity River during the study period ranged from a low of 11,000 acre feet at Goodrich, Texas, for the month of August 1972, to a high discharge in June 1973 of 853,590 acre feet at Liberty, Texas. These data are from published and unpublished records of the U.S. Geological Survey, Water Resources Division. When the daily discharge records for these stations were incomplete, we have taken the liberty of extrapolating conservatively to a discharge rate for the entire month. As shown on Figure 4, the discharge of the river increased steadily during the entire study period. For the 12-month period of July 1972-June 1973, the approximate discharge of the Trinity River was 3,641,000 acre feet at Liberty, Texas--which is approximately 73 percent of a historical mean flow calculated for the years 1941-1968 shown on Figure 29 (unpublished data, U.S. Corps of Engineers, Fort Worth District). Unfortunately, the present study will contribute little to the knowledge of the effects of low flow because even though the river discharged less than 4,000,000 acre feet during the study period approximately 83 percent of that total discharge occurred during the last five months of the investigation, yielding water levels that approached record heights. Rainfall which is normally near 50 inches in the Galveston Bay area was considerably heavier than normal during this period. The observations of this study will necessarily be of effects of high fresh water inputs, although the importance of any study such as this is to come closer to the definition of the relationship of river discharge and the bay ecosystem.

Flow vs. Water Quality

In order to examine the relationship between all water quality parameters and river discharge, mean values of five parameters at all stations, regardless of depth or area, were graphed against mean river discharge (Fig. 30). The value of this set of graphs is to indicate trends rather than direct correlations. Direct correlations between single sets

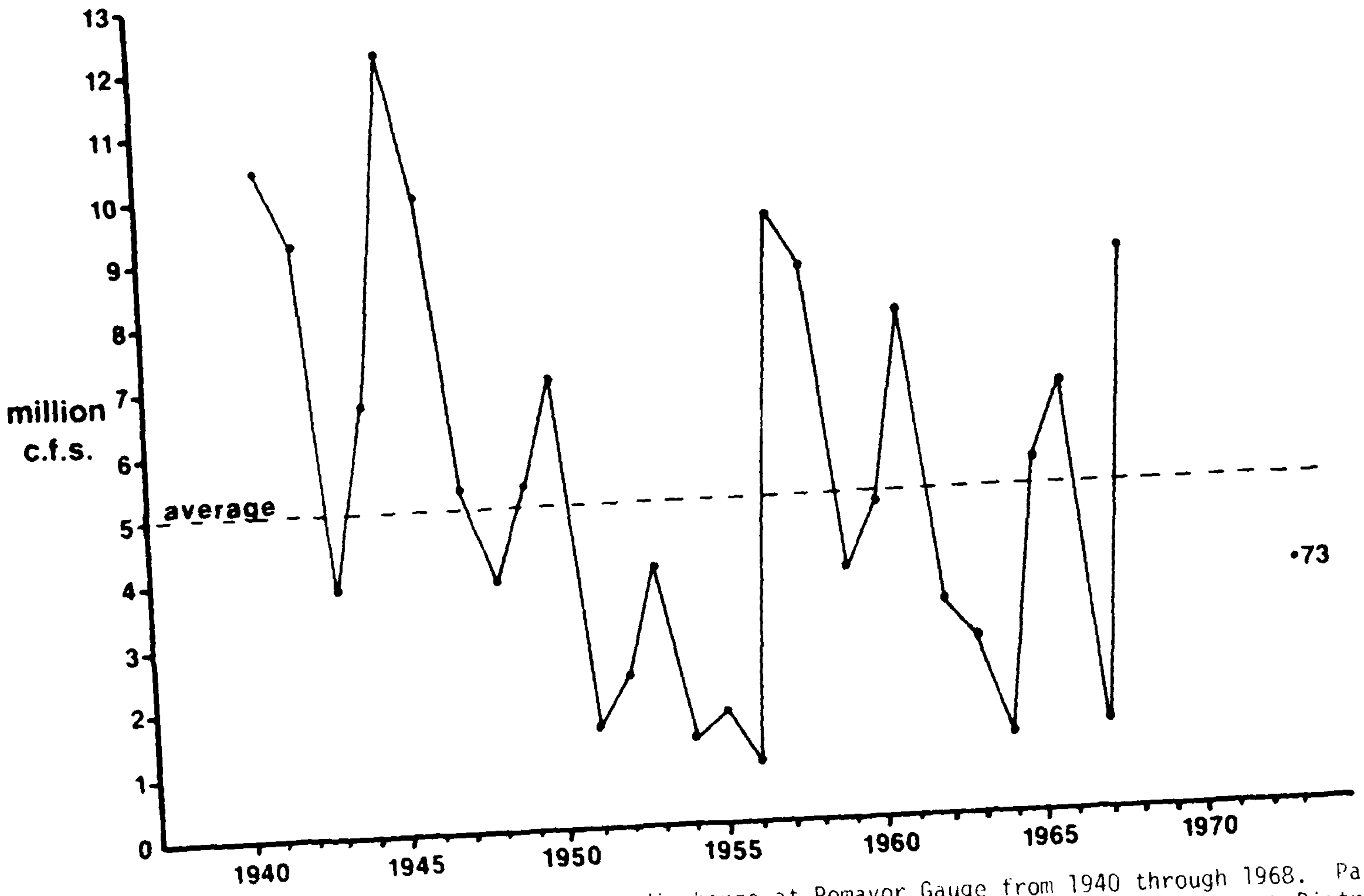
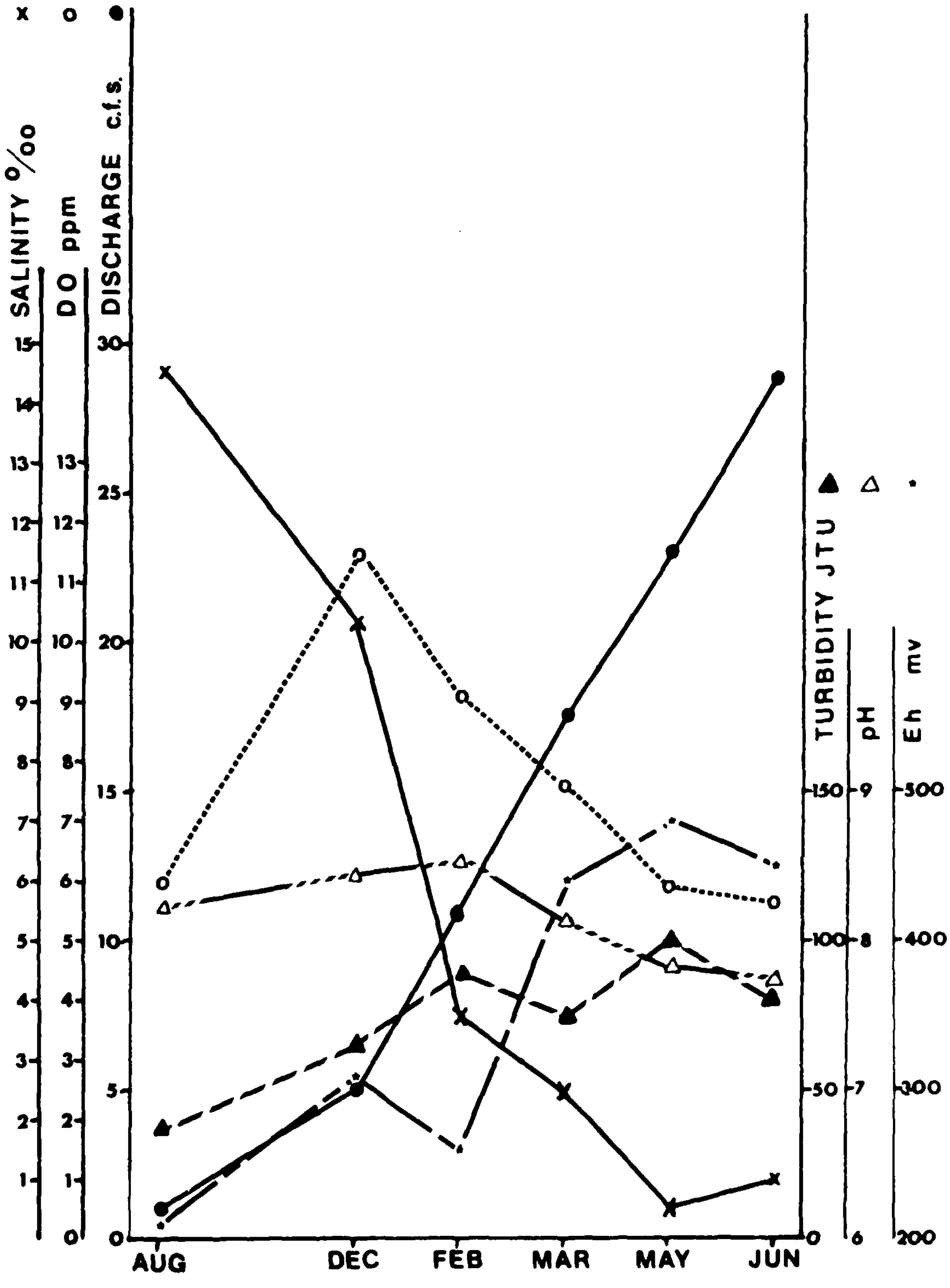


Figure 29. Range of annual Trinity River discharge at Romayor Gauge from 1940 through 1968. Partial (six months) total for 1973 given. Figure compiled by U.S. Corps of Engineers, Fort Worth District.

Figure 30. Comparison of river flow (discharge in c.f.s.) and the mean values at Trinity Bay stations of various water quality parameters, for the sampling period August 1972-June 1973.


SALINITY ‰ x
DO ppm o
DISCHARGE c.f.s. ●
TURBIDITY JTU ▲
pH △
Eh mv •
AUG
DEC
FEB
MAR
MAY
JUN

of variables will be discussed individually under their respective headings.

Temperature

River flow has little or no affect on bay temperatures. If runoff is high in the upper drainage basin in the winter months, cold river water seems to have a little influence downstream. The river flows so slowly that the water largely reflects ambient air temperatures when it enters the bay. Local climatic conditions have the greatest effect on Trinity Bay. Shidler (1961) states that Trinity Bay has a wider range of temperatures than any other part of the Galveston Bay complex. The Texas Water Quality Board (1972) has established criteria that prohibit discharges into Trinity Bay that would raise temperatures more than 4°F above fall, winter, and spring ambient levels, and more than 1.5°F in summer. The Trinity River is not likely to change bay temperatures beyond those figures.

Dissolved Oxygen

Dissolved oxygen also is most affected by local conditions in the bay rather than by influences of the river. A comparison of Figures 5 and 6 shows clearly the inverse relationship between temperature and dissolved oxygen. Dissolved oxygen values range from 3.5 to 20.5 ppm in the bay (Travis, 1972) and supersaturation occurs fairly frequently. Supersaturation is most frequently explained by citing high photosynthetic activity (McFarland, 1963) or extreme surface turbulence combined with low temperatures, as more oxygen can be dissolved in colder waters. Dissolved oxygen is often positively correlated with the pH of waters (Odum, Cuzon du Rest, Beyers, and Allbaugh, 1963) and can indicate significant biological activity (Espey, Hays, Bergman, Buckner, Huston, and Ward, 1971). High biological activity (dependent on high oxygen concentrations) is accompanied by greater respiration rates which yield more hydrogen ion in the waters, therefore lowering the pH. Those same authors state that dissolved oxygen during the last seven years has gradually increased in Trinity Bay. On the other hand, river flow has been quite variable during those same years, indicating that the river has little influence on dissolved oxygen in the bay.

Salinity

River discharges have the greatest effect on salinity in the bay. Figure 30 indicates that an inverse relationship exists between flow and salinity. This relationship has been noted by other authors (Pullen, et al., 1971). Rainfall and the runoff from Double Bayou, Lone Oak Bayou, and Lake Anahuac also contribute fresh water to the bay. The salinity regime of the bay ranges from fresh to salinities of about 20 ^{o}/oo in the upper bay and from 1 to 30 ^{o}/oo at the mouth. Salinity is one of the most important parameters that governs the presence or absence of many species in the bay. More extensive discussion of salinity tolerance and limits of organisms will follow. If river flow is reduced, salinity will usually increase. The National Technical Advisory Committee authored a report (1968) that recommended that the isohaline pattern of an estuary not be altered more than ±10 percent of the natural variation. It could be reasoned that if the 900,000 acre feet discharge of 1956 (Fig. 29) is the extreme low of natural variation, then the Trinity discharge should [illegible] be reduced more than an additional 10 percent, or down to 810,000 acre feet. Therefore, based on historical data (Reid, 1955) and the recommendation of the National Technical Advisory Committee (1968), the flow of the Trinity should be maintained to keep the salinities in the upper bay below 22 $^{0}/oo$ and in the lower bay below 33 $^{0}/oo$. However, it is doubtful if salinities in lower Trinity Bay could ever reach 33 $^{0}/oo$, as the Gulf waters off Galveston rarely exceed 33 $^{0}/oo$ because of salinity depression resulting from the Mississippi River discharge being carried west towards Texas by longshore currents.

Hydrogen Ion Concentration

The hydrogen ion concentration or pH is affected somewhat by river discharge simply by dilution because fresh water areas generally have lower pH's than marine areas (Parker and Blanton, 1970). However, the pH of a bay is subject to greater influence by constituents of the river discharge in combination with the localized water chemistry of the bay. The factors affecting pH are acids; acid generating salts, and free CO_2 that enter the water column; and carbonates, bicarbonates, hydroxides, phosphates, and borates that serve to bind up and remove H^+ ions from the water column through various chemical actions (Blakey and Kunze, 1971). The higher the pH of rivers, the richer they are in carbonates, bicarbonates, and associated salts (Smith, 1966). The high ion content of saline waters tend to buffer the waters against extreme pH fluctuations. The Galveston Bay system is highly buffered but does exhibit a large diurnal pH fluctuation occurring simultaneously with a dissolved oxygen fluctuation resulting from high biological activity (Espey, *et al.*, 1971).

The CO_2 resulting from high respiration rates aids in the promotion of solubility of phosphorus (P) into solutions more adapted to biological assimilation (Fuller, 1972). Respiration uses oxygen and liberates hydrogen ions which can lower the pH and Eh (Brooks and Kaplan, 1972). The significance of a drop in pH is that it usually increases the availability of most nutrients to plants (Smith, 1966). These three elements of the bay ecosystem (pH, O_2, and P) vary from hour to hour, but also maintain their interrelationships at any point in time (Odum, *et al.*, 1963). These three parameters are compared in Figure 31, which shows a fair amount of correlation for the mean values during the study period.

The National Technical Advisory Committee (1968) recommends that the pH in the salt water portions of tidal tributaries and coastal waters should not be altered more than ±0.1 pH unit from the normal range of values. Records of pH in Trinity Bay show a range of values from 6.2 to 9.4 (Travis, 1972) and since pH in the Trinity River is within that range, ranging from 7.2 to 9.2 (Dupuy, *et al.*, 1970), it is doubtful that the river could ever be the cause of excessive pH fluctuations.

Reduction-Oxidation Potential

Reduction-oxidation potential (Eh) is little studied as a water quality parameter. It was first believed that Eh was the addition to or loss of O_2 from a substance. This was modified to the belief that Eh measured the addition to or loss of H^+ from a substance. It is now believed that oxidation means losing electrons and reduction is the gaining of electrons (Zobell, 1946). The presence of oxygen and the pH level of the

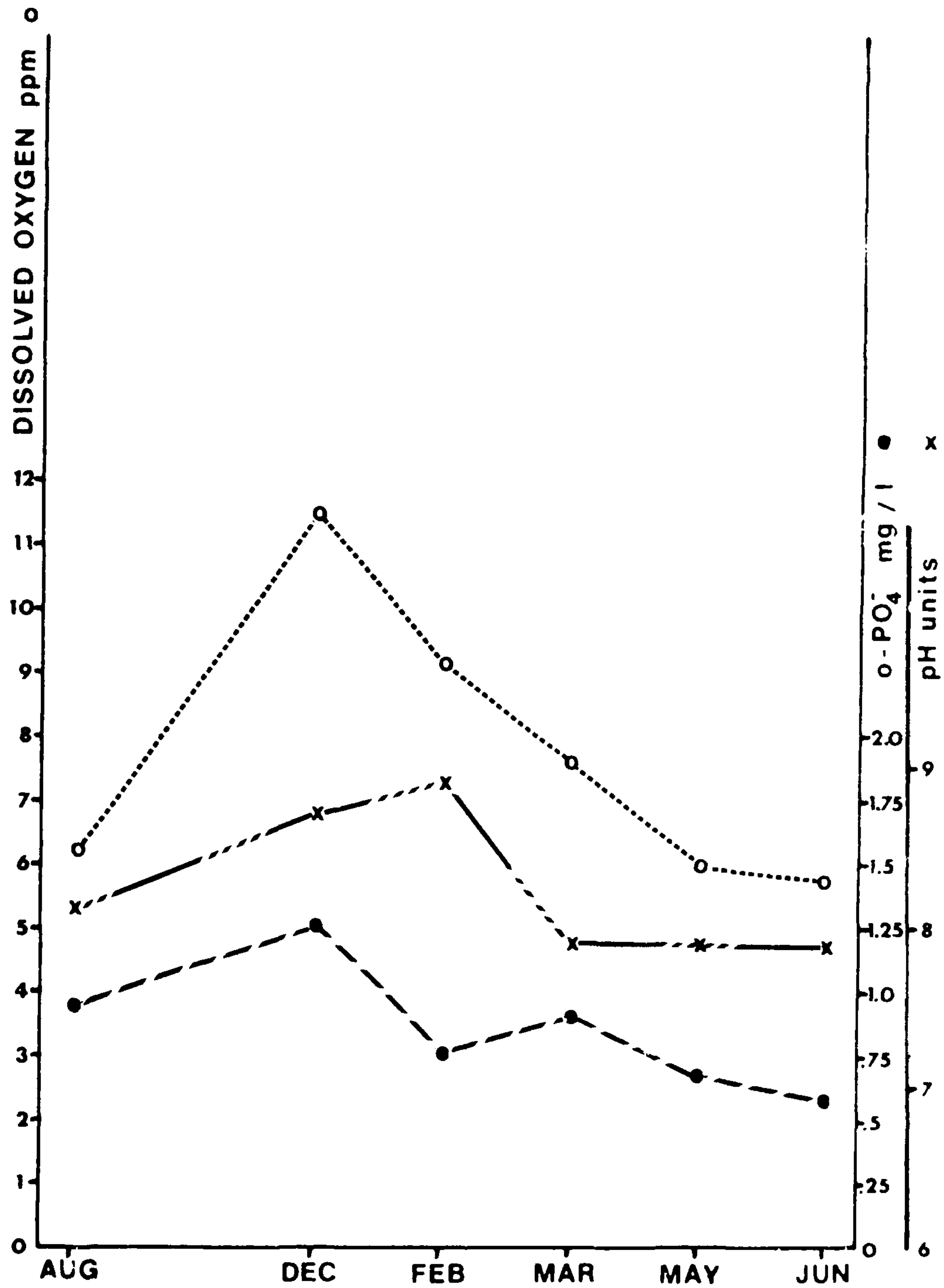


Figure 31. Comparison of average Trinity Bay values for pH, DO, and o-PO_4 from August 1972-June 1973.

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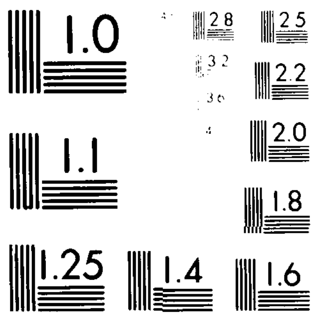


MICROCOPY RESOLUTION TEST CHART

environment are probably the two most important factors governing Eh. The relationship between pH and Eh is linear when the dissociation constant of the reactant is small compared to the H^+ ion concentration (Zobell, 1946). The author also cites a multiple and unpredictable effect on Eh by temperature. Brooks and Kaplan (1972) state that Eh will be high or will be lowered by a rise or drop in pH, respectively. Circulation and oxygenation are probably the two most important ingredients in determining oxidizing or reducing conditions in estuaries. The mean Eh values in the marshes were usually lower than those in the bay. We believe this reflects the fact that there is less circulation and mixing in the constricted waterways of the marshes. River discharge has little effect on dissolved oxygen, but has a great effect on circulation in the bay and might therefore have an effect on the Eh in Trinity Bay. If river flow was reduced, the circulation patterns might change and allow areas of relatively still water under quiet meteorological conditions, and thus could contribute to lower Eh values--perhaps even to reducing conditions.

Turbidity

The discharge of the Trinity River does have a significant effect on turbidities in the bay since it is the largest source of suspended sedimentary materials for the bay. Depending on whose sources are used, the Trinity River is believed to deliver from 3,000 to 7,260 acre feet of sediment per year into Trinity Bay (Lankford, *et al.*, 1969), while Rehkemper (in Lankford, *et al.*, 1969) believes an intermediate value of about 5,000 acre feet per year is most likely. Much of this material is fine grained and remains in suspension for long periods of time.

Additionally, the shallow depths and considerable wind induced wave action can resuspend much of that material that eventually settles out. Cuzon du Rest (1963) observed a direct correlation between runoff and turbidity but qualified it by stating that the Gulf being calm also contributed to lower turbidities. Lankford, *et al.* (1969) believes the amount of sediment carried into Galveston Bay from the sea is very small. Parker, *et al.* (1969) cited a correlation between high flows and high silt loadings and between low flows and high sand loadings. While the turbidities as seen on Figure 30 do appear to correspond with the river flow, the increase in turbidities is not proportional to the increase in river flow, perhaps because saline water tends to flocculate particulate matter and thus reduce turbidity. It is reasonable to believe that winds, waves, and currents have a greater effect on suspended materials once they reach the bay than does the flow of the river. Even though a reduced flow of the Trinity River would reduce the amounts of sediments delivered to the bay, turbidities in the bay would probably remain essentially unchanged; therefore, the flow would have little effect on photosynthetic activity in the bay.

Metallic Ions

The suspended material carried by the river is also a good source of metallic ions for the bay. The effect of river discharge on concentration of metals in the bay is not apparent when comparing Figure 4 with Figure 10. Mercury values were high early in the study but dropped rapidly and stabilized at 0.2 ppb. Zinc normally occurs in marine waters at a concentration of 0.01 ppm (Curtis, 1972) and the activities of man are generally held accountable for the higher values of zinc found in estuaries. Most river-borne iron precipitates when it reaches the sea (Lepp, 1972), so that perhaps the observed increase of iron in the bay does indicate a contribution by the high flow of the Trinity in June, but our data is not conclusive. In other Texas river estuaries, zinc and iron were observed to range from 5 to about 20 ppb (Parker, *et al.*, 1969). The concentrations of zinc and iron in this study were an order of magnitude larger but our data do not indicate the probable sources of these metals other than the Houston Ship Channel. Parker, *et al.* (1969) also observed copper in Texas rivers, in concentrations ranging from 4 to 19 ppb. Those authors cited that an inverse relationship exists between copper ions and flow rate, with increased concentrations occurring toward the river mouth. This would indicate the sea water is the source of copper. Both copper and lead remained at concentrations below the level of detection of our atomic absorption spectrophotometer throughout this investigation.

Magnesium and calcium ion concentrations and the calculated Mg/Ca ratios were monitored during this investigation and comparisons can be made of Figures 11 and 12 with Figure 4. These data indicate that an inverse relationship exists between river flow and the concentration of magnesium. As the concentrations of calcium remained quite stable, the concentration of magnesium also controlled the Mg/Ca ratio. The Mg/Ca ratio of sea water is 3.12 (Parker and Alderson, 1972) so that the ratio (6.2) observed in December can be considered excessive. Fresh waters almost always have an excess of calcium over magnesium. Magnesium ion concentration is a direct result of the salinity gradient and the constancy of composition of sea water; therefore, high values in December are difficult to explain because salinities had decreased since August when salinities were higher but the Mg/Ca ratio was lower.

The magnesium and calcium ions measured in the marsh samples were more stable throughout the study than those values obtained from the bay stations. Because the Mg/Ca ratios are governed by the salinity gradient and thus by fresh water inflow, any reduction in Trinity River discharge would serve to raise salinities and raise Mg/Ca ratios. The effect of this rise on productivity in the bay is unknown. It is reasonable to assume that higher salinities and higher Mg/Ca ratios would make the bay more attractive to more marine species, both for osmotic and physiological reasons, and perhaps make the bay less attractive to the oligohaline species now utilizing it during portions of the year.

Flow *vs.* Nutrient Factors

One of the primary questions to be answered in this study is whether or not the Trinity River controls the nutrient budget of Trinity Bay. The general relationships between river discharge and all observed nutrient factors are shown on Figure 32.

Nitrates Plus Nitrites

The primary sources of nitrogen are decaying organic matter, sewage, fertilizers, and soil (Blakey and Kunze, 1971). Almost all nitrogen enters estuaries in runoff from the land (Copeland, *et al.*, 1972). Copeland and Fruh (1970) found inorganic nitrogen in Trinity Bay in concentrations less

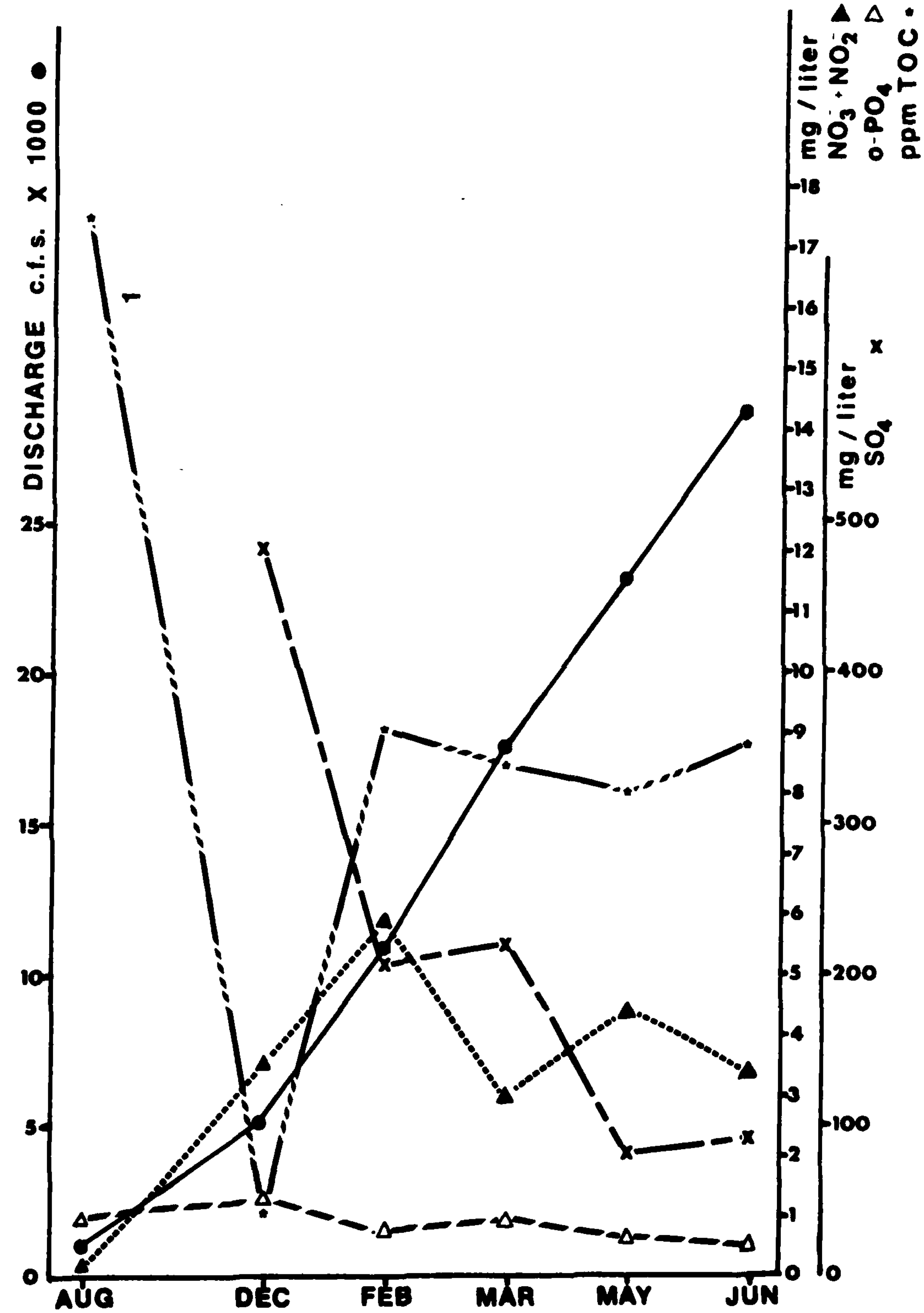


Figure 32. Comparison of river discharge by months with mean values of various nutrient factors in Trinity Bay stations, August 1972-June 1973.

than that considered necessary for phytoplankton growth. Several other authors also believe Trinity Bay to be at or near being nitrogen limited (Espey, *et al.*, 1971; Brooks and Kaplan, 1972). The process that prevents rapid depletion of nitrogen is rapid regeneration of nitrogen in the upper layer by grazing zooplankton (Carpenter, Pritchard, and Whaley, 1969). Davis (1971) concluded that rivers contribute the greatest amount of estuarine nitrogen but that the significant point in the cycle was retention time in the bay. He believed nutrients carried by low flows offered little benefits and those carried by flood waters did not remain in the estuary long enough to benefit the biota. The concentrations observed during the study period (Fig. 13) do not correlate well with river flow but appear somewhat stable in spite of high flows from March to June. There was no demonstrable enrichment with depth as many surface and bottom stations showed a reversal of their concentrations of nutrients each sampling period. Pullen, *et al.* (1971) believe that if the Trinity flow is reduced and the influence of Gulf waters increase in Trinity Bay, then nitrogen concentrations are going to be reduced. Similarly, Copeland, *et al.* (1972) cited a correlation between high concentrations of nitrogen and high river flows. Since much of the opinion cited above indicates that runoff and river flow are the major sources of nitrogen, it is reasonable to assume that reduced flows will yield reductions in the concentrations of nitrogen. If such were the case, it would almost guarantee that Trinity Bay would be nitrogen limited and probably dependent upon river discharge for nitrogen renewal.

Orthophosphates

A guideline for a minimum concentration of phosphorus necessary for phytoplankton growth is 0.01 mg/liter as reported by Copeland and Fruh (1970). All of the orthophosphate values measured in this investigation were above that low level, and as orthophosphates are but a portion of the total phosphorus, the amounts of phosphorus in the bay were always above the minimum guideline. Brooks and Kaplan (1972) believe that phosphorus could become a limiting nutrient while Espey, *et al.* (1971) state that the general trend in phosphorus concentrations over the last six years in Trinity Bay has been increasing towards those levels which could now support "blooms" of phytoplankton. Redfield, Ketchum, and Richards (1963) state that nitrogen would always be used up before phosphorus could become limiting. Sabine Lake and Matagorda Bay were characterized by PO_4 concentrations similar to those found in this study (Hahl and Ratzlaff, 1970), as were the Brazos and Colorado Rivers (Parker, *et al.*, 1969). It is possible that there is some enrichment with depth, as the mean concentration of o-PO_4 was higher for bottom stations than for surface stations in four of the five sampling periods for which there are data. In order to completely define phosphate enrichment at depth would require several samples at evenly spaced intervals throughout the water column at each station. Pullen and Trent (1969) and Pullen, *et al.* (1971) did not observe any correlation between phosphates and river flow rates but summarized their investigation by stating that if flows decreased and the influence of Gulf waters increased, then phosphorus levels would decrease. Those authors also stated that high values of phosphorus usually followed high river flows. The values observed during this study decreased only slightly in spite of high river discharges. If the river was the primary source of phosphates, then concentrations should have increased with increased flows. If the source of phosphates was not in the river, then phosphate concentrations should have been reduced because of dilution by the high river flow. It appears that phosphates are influenced more by natural biochemical processes in the bay than by the flow of the river, but since the river is one of the largest sources of phosphates into the bay, flow reductions would no doubt cause reductions in phosphate concentration.

Sulfates

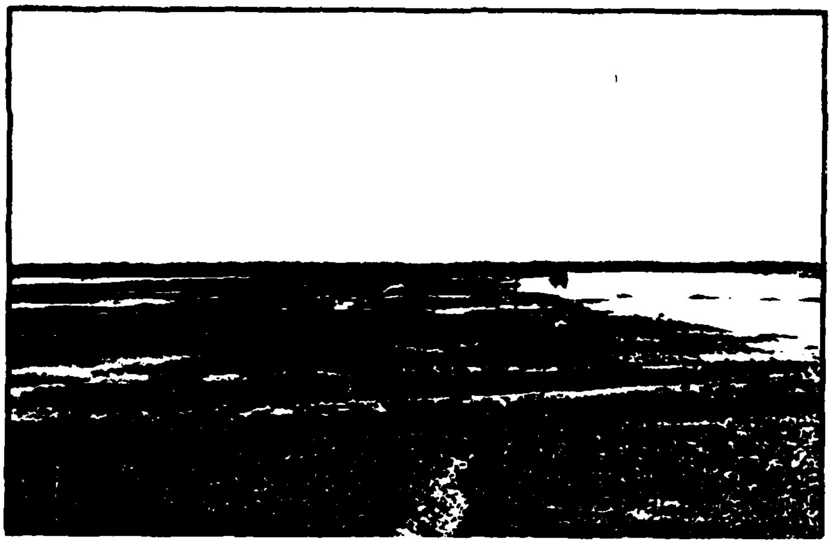
The sulfate ion is the inorganic form of sulfur used by green plants and phytoplankton to satisfy their growth requirements. The values of sulfate concentrations shown on Figure 32 decreased throughout the study period, except during March. Compared to the Trinity discharge, the sulfate concentrations appear to be inversely correlated. Whether this inverse correlation is dilution of sulfates in the bay or an influx of sulfates from Gulf waters is not known. The Texas Water Quality Board (1972) set the maximum allowable sulfate concentration for Trinity Bay at 700 mg/liter. It was only during December 1972 that sulfate values in Trinity Bay ever approached that level.

Total Organic Carbon

In a year's time, the photosynthetic organisms in a square meter of open sea surface can assimilate from 100 to 200 grams of carbon (Vishniac, 1968). This sizable production is almost completely reoxidized each year by the *primary consumers and decomposers* (Wehmiller, 1972). In addition to phytoplankton production within estuaries, the emergent and marsh grasses make a sizable contribution of organic carbon to the waters and the sediments (Volkmann and Oppenheimer, 1962). It is quite possible that the increase in total organic carbon values during the February sampling trip and the remainder of the investigation was due to massive flushing of organic matter from marshes to the bay. Between the December and February sampling trips, large areas of the marshes that were covered by alligator-weed were almost completely denuded of the winter's accumulation of dead vegetation. The vegetation during the height of the spring growth in May is compared with the denuded condition of March at the same location (Fig. 33). This same phenomenon was also noted in a report by the Division of Natural *Resources and the Environment*, University of Texas (Fruh, 1972).

Normal concentrations of TOC in sea water are near 3.12 mg/liter (Sverdrup, *et al*, 1942) while TOC values in some Texas bays range from 4 to 7.5 mg/liter (Wilson, 1961, 1963). The Trinity Bay total organic carbon values observed in August 1972 were very high and no explanation for their high levels can be offered. Morris and Foster (1971) observed a winter minimum and then a gradual increase to a fall maximum in an European estuary, the Menai Strait. Perhaps the August maximum and December minimum observed in Trinity Bay are analogous to those of the Menai Strait. Morris and Foster (1971) also stated that rivers are generally higher in organic carbon than oceanic waters. If this is the case, and with respect to flood waters flushing out organic matter *from the marshes*, it appears

A. High growth of alligator-weed in May 1973



B. Little growth of vegetation, March 1973

Figure 33. Comparison of seasonal vegetation cover at Trinity marsh station 26.

that reduced river flows would serve to reduce organic carbon in the bay. However, it is unlikely that flood waters could ever be prevented from flushing the marshes.

The comparison of total organic carbon versus flow on Figure 32 shows little correlation. From February on, the concentrations of TOC remained fairly stable in spite of increased flow. Total organic carbon and the production of marsh vegetation are compared on Figure 34, which illustrates the large decrease in marsh vegetation between December and February with the increase in TOC at the same time. However, this inverse relationship was not maintained throughout the study. It was mentioned in the results section (p. 40) that the percentage of total carbon that was organic increased throughout the study and correlated well with river discharge (compare Fig. 4 and Fig. 16). This lends further support to the possibility that much of the organic carbon was entering the bay (from the river) and marshes (from other sources) rather than being produced primarily in the bay or marshes. These data plus the observations of Morris and Foster (1971) and Wilson (1961, 1963) that rivers are higher in organic carbon than sea water indicate that reduced river flows would tend to lower the concentrations of total organic carbon in Trinity Bay.

Flow *vs.* Biological Factors

The general relationships of salinity to the several biotic communities are shown on Figures 35 and 36. Salinity is plotted against the biotic community levels rather than flow because the salinity gradient is one of the three most important factors--salinity, dissolved oxygen, and

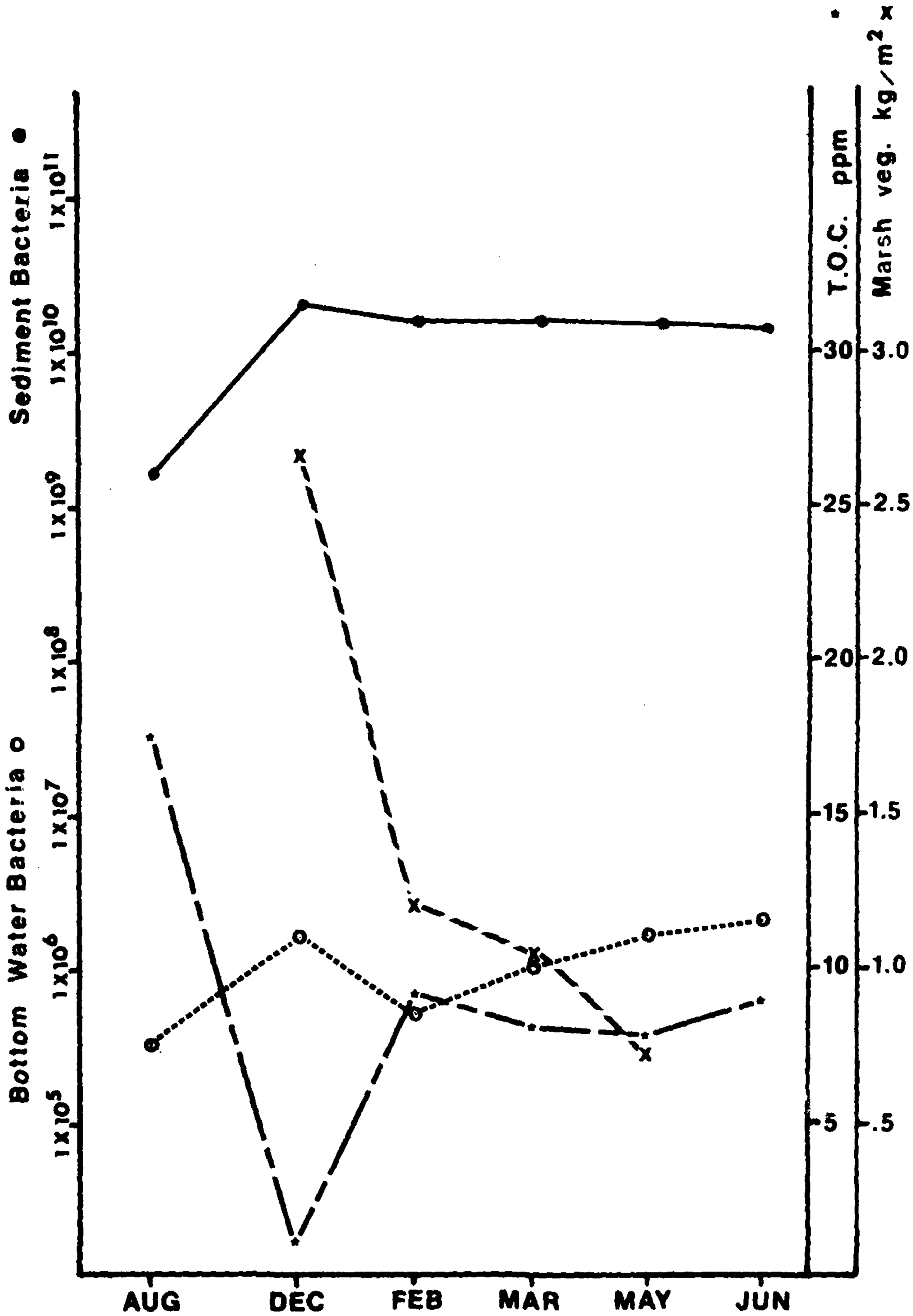


Figure 34. Comparisons between mean bacterial counts from water and sediment samples in the Trinity Bay region and total organic carbon concentration and standing crop of marsh vegetation, August 1972-June 1973.

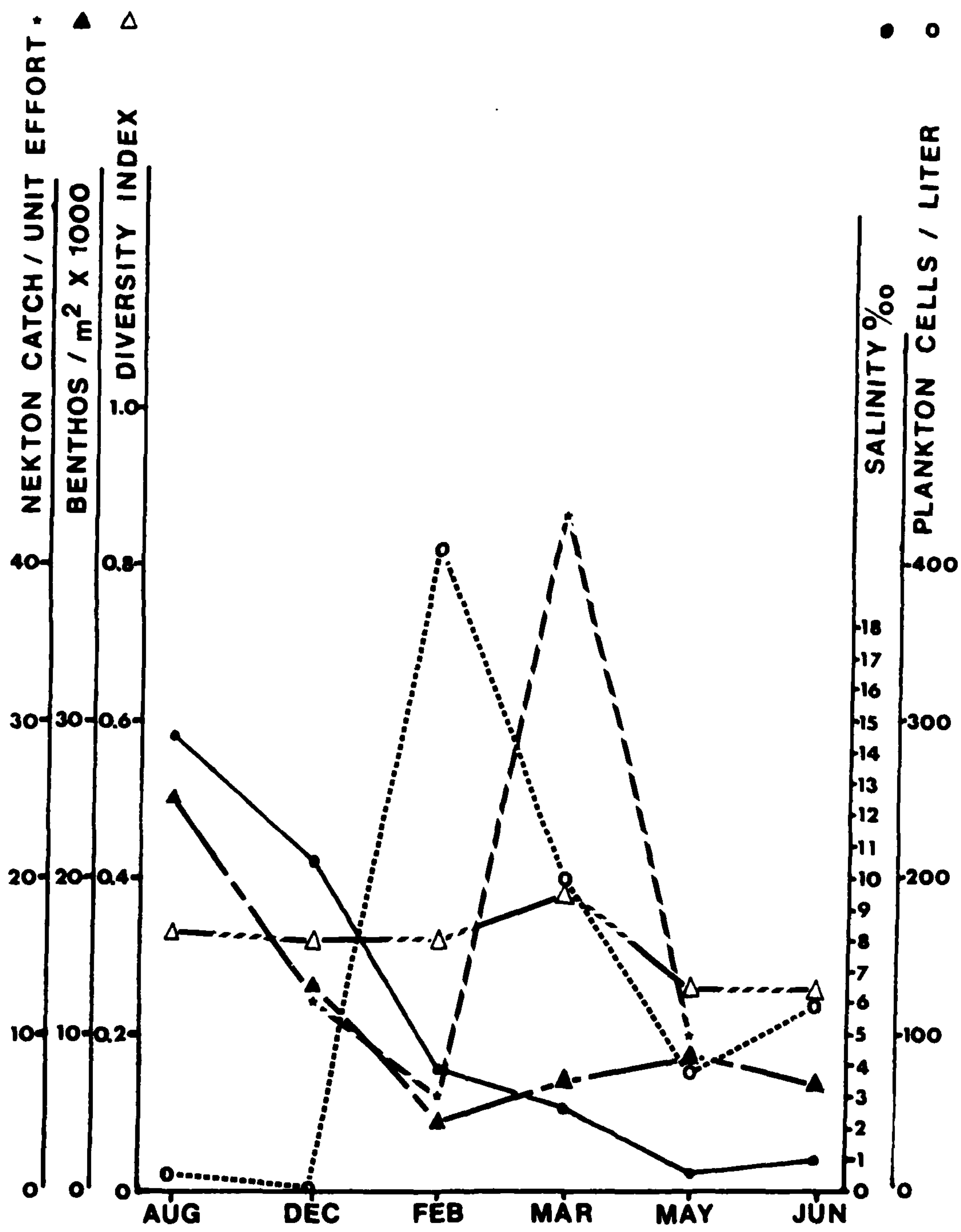


Figure 35. Comparisons between benthic invertebrate and plankton mean counts, benthic diversity, nekton catch per unit effort, and salinity variations in Trinity Bay, August 1972-June 1973.

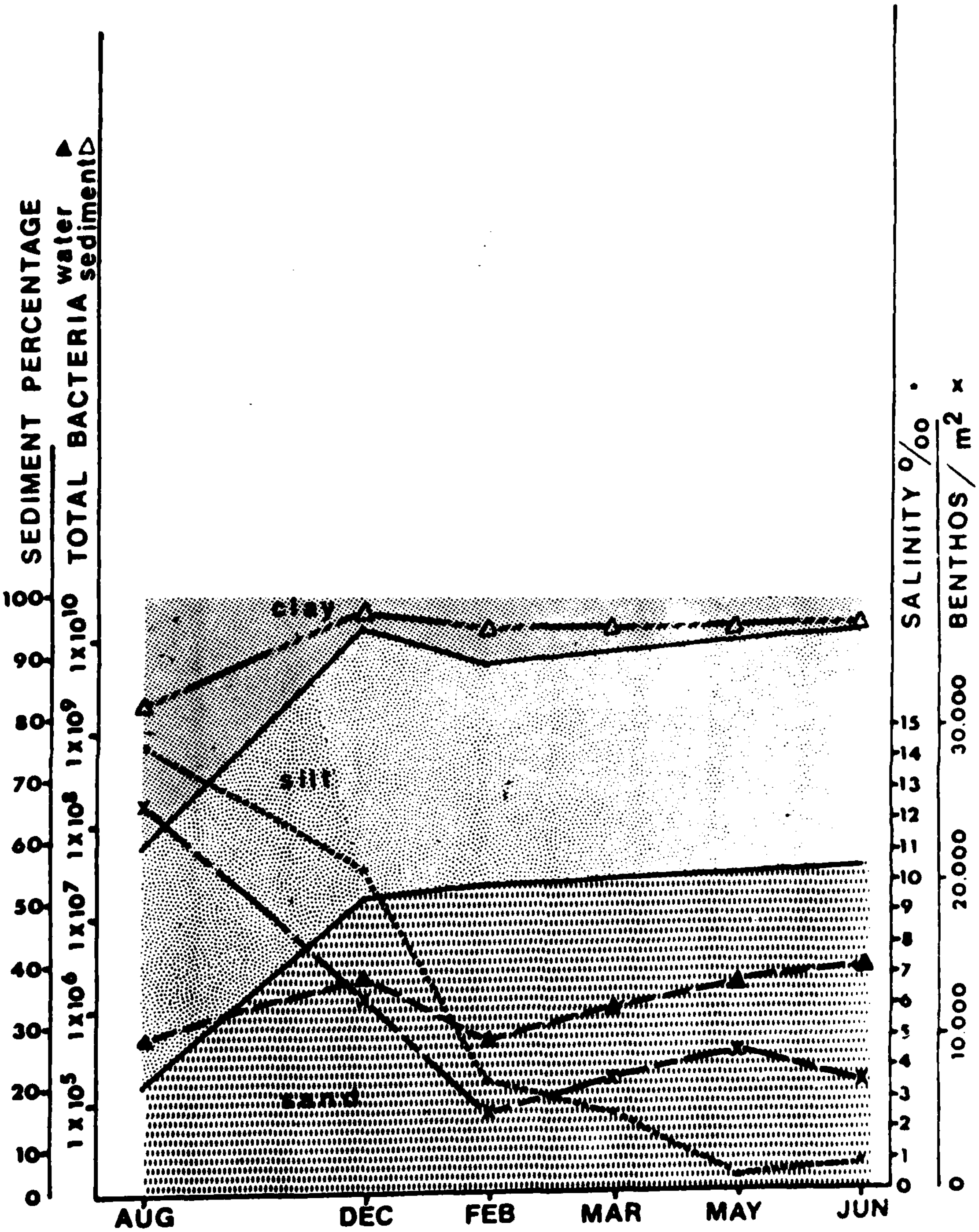


Figure 36. Comparisons between sediment changes, sediment bacterial counts, benthic standing crops, and salinity as averages for Trinity Bay stations, August 1972-June 1973.

temperature--controlling the biota (Copeland and Fruh, 1970) and is inversely proportional to river flow.

Bacterial Populations

The bacteria in Trinity Bay occur in relatively high numbers. High coliform counts occurred mainly in the marshes, the periphery of the bay near the marshes, in the river channel near the village of Anahuac, and in or near the channel from Double Bayou. The high coliform counts are attributed to animal wastes in the marshes and sewage wastes from Anahuac and Double Bayou. The Texas water quality standards (Texas Water Quality Board, 1972) allow no more than 100 coliforms per 100 ml for the Trinity River when used for raw water supply, and no more than 70 coliforms per 100 ml in Trinity Bay. The Texas Department of Health closes the bay to oystering when the most probable number of coliforms of all sample stations average 100/100 ml.

The total bacterial counts in the water samples taken during this study were lowest in August 1972 and highest in June 1973. This is not in agreement with Volkmann and Oppenheimer (1962) who observed highest total bacterial counts in October and lowest in February, increasing steadily through the spring apparently in response to temperature. There is a general increasing trend in our own counts from February to June that could be a growth response to temperature. The total counts in Trinity Bay waters were somewhat lower than those found in Laquna Madre and Redfish Bay by Oppenheimer and Jannasch (1962). Those authors assumed that bacteria comprise three percent of the total particulate load in Redfish Bay waters. They admitted that it was an assumption, but the importance of the assumption cannot be ignored. If such amounts of bacteria do exist in suspension, they will definitely be utilized by some invertebrates as food. Some aquatic invertebrates can not only digest and assimilate bacterial cells but can live on an exclusive diet of bacteria (Zhukova, 1963; Zhukova and Fedosov, 1963; and Hayes, 1963). The total counts in Trinity Bay sediments, on the other hand, were very high, much higher than the Brazos and Colorado estuaries which had ranges of 1×10^8 to 3×10^9 (Parker, *et al.*, 1969). Bacteria in the sediments of Trinity Bay were three orders of magnitude greater than those in the water column. Oppenheimer and Jannasch (1962) observed this same phenomena but did not find the same orders of magnitude difference. The finding of bacteria in the sediments in numbers near 1×10^{10} is very significant. If one assumes that a bacterium occupies approximately one cubic micron of volume, then 1×10^{10} bacteria occupy 0.1 percent of a cubic centimeter which is 1×10^{12} cubic microns in volume. This can mean that at certain times under certain conditions 0.1 percent of the surface sediments could be live bacteria. Kriss (1959) defined the biomass of one bacterium as 2×10^{-13} grams. On that basis, the bacterial population of Trinity Bay would have a biomass of 2,000 g/m^3. Since bacteria occur only in the top few centimeters of sediments, this value on a square meter basis would be 20 g/m^2. This amount of organic matter per square meter per day is easily enough to serve as the basis of a benthic food chain. That the bacteria in the sediments remained in stable numbers indicates there is a balance between nutrition and predation of the bacteria.

The bacterial populations of Trinity Bay are compared with TOC on Figure 34. This comparison is made simply because bacteria are the primary decomposers in the ecosystem and, as such, are crucial in reoxidizing organic matter. Oppenheimer and Jannasch (1962) believe the assumption can be made that bacteria themselves are approximately 5 percent organic carbon, and because of their significant biomass in Texas estuarine sediments, approximately 7.2 percent of the organic carbon in the estuaries is derived from bacteria. Culpepper, *et al.* (1969) state further that total direct counts of bacteria can be converted to bacterial organic carbon by using Zobell's Constant; *e.g.*, $Co = n(2x10^{-11})$ where Co = mg organic carbon/cc sediment, and n = cell count. A possible inverse relationship between TOC and bacteria in the water column is indicated on Figure 34. The high populations and biomass of the bacteria, plus the large amounts of organic matter flushed into the bay, and a possible correlation with total organic carbon all lend further support to the thesis offered by Parker, *et al.* (1972) that bacteria may form the base of primary production in Trinity Bay, and perhaps other Texas bays, too. High turbidities and low plankton populations in Trinity Bay suggest that photosynthesis could not account for enough of the primary production in the ecosystem to support the tremendous total productivity of the bay system.

Plankton Populations and Chlorophyll-a Productivity Relationships

Plankton populations in Trinity Bay were observed by us to be very low; the low levels have been observed by other authors as well (Copeland and Fruh, 1970; Mackin, 1971). Mackin (1971) stated that zooplankton populations tended to exceed phytoplankton populations in Trinity Bay, but that the phytoplankton populations were more diverse. The relationship between net plankton and nannoplankton in Trinity Bay is not well defined. Generally, nannoplankton is responsible for most of the summer respiration and can contribute up to 95 to 98 percent of the production in algae "blooms" (McFarland, 1963; Rodhe, Vollenweider, and Nauwerck, 1958). Nannoplankton was not collected during this study so that values for the plankton populations represent only a portion of the total present. The water samples used for the studies of production of chlorophyll-a did include nannoplankton, as they were simply dipped from the surface. The data from the studies of chlorophyll-a production are presented in Table 5. The very great difference between phytoplankton populations and chlorophyll-a production as shown on Figure 20 can be explained by several processes. One explanation for the contrast between population size and productivity is the retention time of the plankton in relation to flow and circulation (Marshall, 1956). Another source of variation in production figures is the efficiency of the photosynthetic process. Normal photosynthetic efficiency in marine estuaries of Texas is from two to four percent of the visible light received (Odum, *et al.*, 1963). In addition, the rate of light-saturated photosynthesis will vary considerably, even with the same concentration of chlorophyll-a present. The efficiency of productivity is depth dependent too, as chloroplasts tend to break down as a result of too intense light levels at the surface (Marshall, 1956). Our samples for chlorophyll determinations were collected at the surface. Morris and Foster (1971) summarized this relationship by saying that primary productivity can be high while chlorophyll concentrations are low because of immedate further biological utilization and a reduction in the amount of chlorophyll per cell

TABLE 5

PRODUCTION OF CHLOROPHYLL-a IN
TRINITY BAY SURFACE WATERS

Month	Station	Chlorophyll-a at start μg/liter	Chlorophyll-a after 24 hours μg/liter	Production μg/liter/day
December	1	1.31	12.50	11.19
	6	0.02	0.08	0.06
	7	7.70	12.90	5.20
	11	0.50	0.60	0.10
	16	0.50	0.70	0.20
	34	0.20	1.09	0.89
	38	1.09	1.17	0.08
February	9	0.09	0.40	0.31
	13	0.20	0.50	0.30
	18	0.80	0.64	-0.16
	21	1.08	1.80	0.72
March	1	0.30	0.80	0.50
	5	0.40	0.60	0.20
	9	0.30	0.60	0.30
	13	4.41	9.25	4.84
	16	5.67	6.49	0.82
	45	0.30	0.50	0.20
May	5	0.20	0.30	0.10
	9	0.20	0.40	0.20
	10	0.10	0.30	0.20
	16	0.90	1.83	0.93
	45	0.20	1.08	0.88
	50	0.30	0.40	0.10
June	1	0.10	0.20	0.10
	36	0.40	0.60	0.20

in the summer. They continue by saying that spring and summer increases in production are due to the use of dead and decaying cells as a carbon source in excess of the supply from bacterial and chemical oxidation. In effect, there is rapid production with a small standing crop. Chlorophyll-a has been correlated with flow and temperature in the Guadalupe River system (Young, Whiteside, Longley, and Carter, 1973), but that relationship does not hold true in Trinity Bay, as can be seen on Figure 37. Except for the period from February to May, the chlorophyll-a curve followed that of dissolved oxygen, and was inversely related to river flow. Unfortunately, the data are not definitive. A direct relationship between chlorophyll-a and orthophosphate concentrations can be seen on Figure 38. The phosphate concentrations did not vary greatly, but they did fluctuate simultaneously with chlorophyll-a. Phosphates are extremely important in the phosphorylation mechanism in the photosynthetic process and this importance could be reflected in the correlation of chlorophyll-a and orthophosphate concentrations. In contrast, phosphates and total plankton populations are very poorly correlated in an inverse relationship.

Other relationships between plankton and other parts of the ecosystem that should be noted are with the two nutrients, organic carbon and nitrogen. Planktonic photosynthesis is an important source of organic carbon for the ecosystem. The relationship of plankton populations to total organic carbon can be seen on Figure 38. The correlation is direct, but not close. The two parameters fluctuate in the same direction but nowhere near proportionally. Organic carbon from the river and marshes is surely the source of the large carbon fluctuations rather than planktonic photosynthesis.

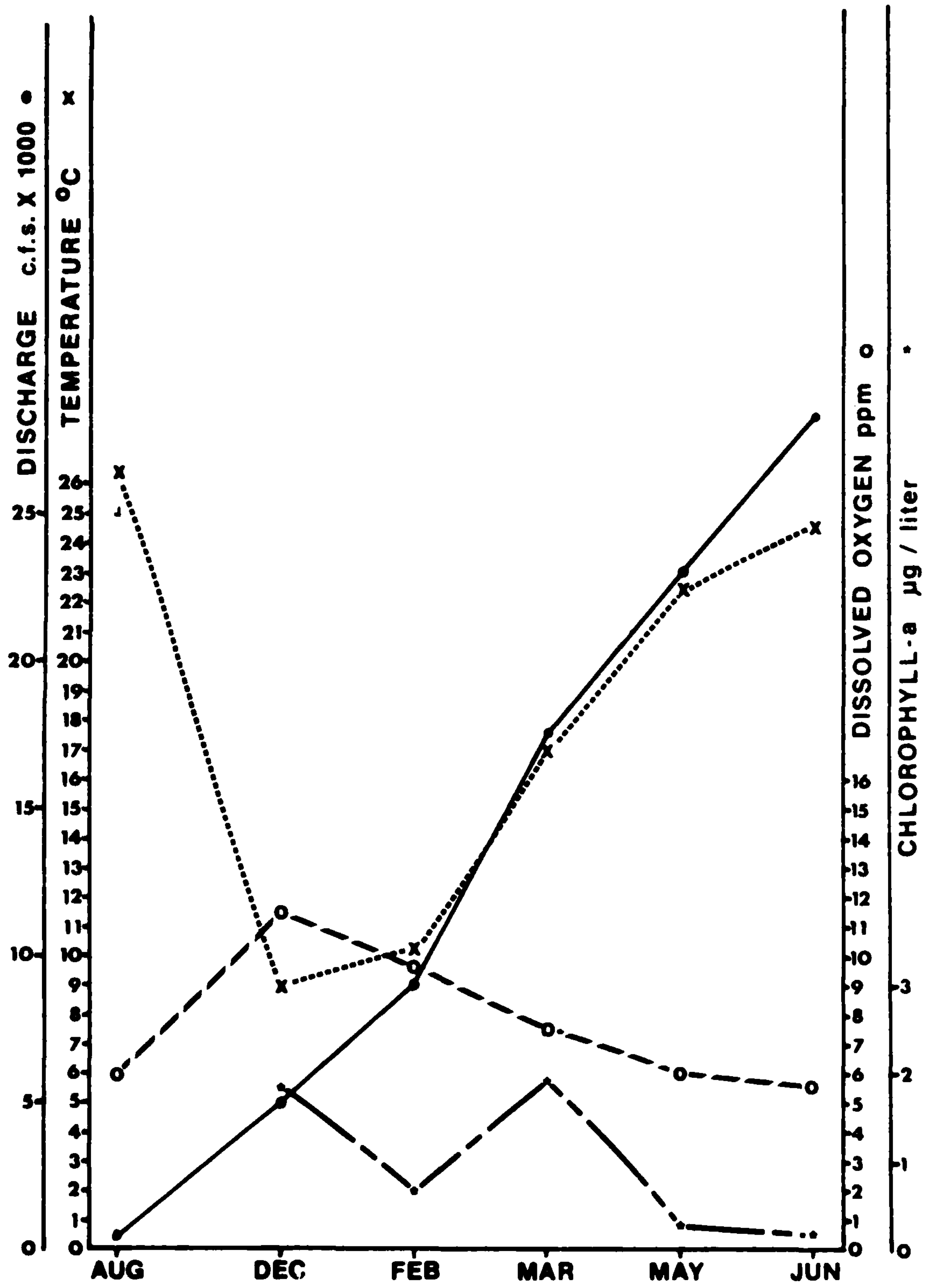


Figure 37. Comparisons of average values for Trinity River discharge and Trinity Bay temperature, dissolved oxygen, and chlorophyll-a production, August 1972-June 1973.

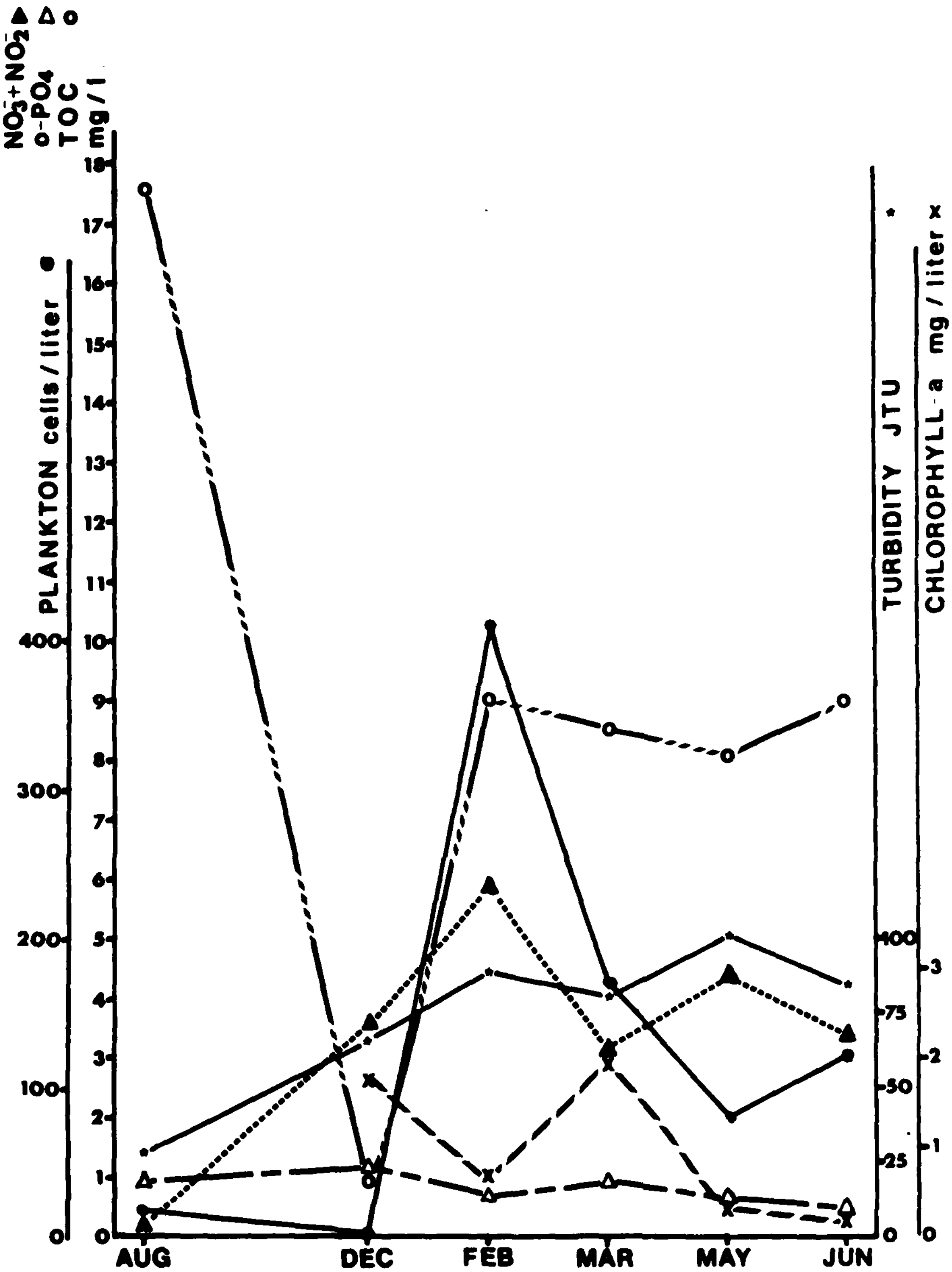


Figure 38. Comparisons between average phytoplankton counts and those factors usually associated with phytoplankton growth and reproduction (nutrients, chlorophyll-a production, and turbidity, August 1972-June 1973.

Data shown on Figure 38 indicate a puzzling lack of correlation between phytoplankton and NO_3^- and NO_2^- ions. Copeland and Fruh (1970) cited that a close correlation exists between nitrogen and plankton, but these relationships were not evident in the present study.

Marsh Vegetation

Several types of marshes have been defined and delineated in the literature of the Trinity Bay area. All the marsh definitions are based on salinity characteristics, although the salinity ranges of each type of marsh are not included. Fisher, McGowen, Brown, and Groat (1972) delineated a salt water marsh, brackish to fresh water marsh, closed brackish water marsh, and fresh water marsh in the Trinity Bay region. We contend that without accompanying salinity ranges for each type of marsh, they are useless definitions. All marshes adjacent to northwest Trinity Bay should be defined as either fresh water marshes, or fresh to medium salinity marshes. The salinities at the head of the bay never exceed 20 $^o/oo$ and there is a constant hydraulic head that maintains even lower salinities in the marshes. The hydraulic head is smaller in the marshes west of the delta area than in the delta itself, but is still able to maintain lowered salinities. For further references on marsh plants in the Trinity Bay region see Sperry (1949), Renfro (1959b), Singleton (1961, 1965), Pullen (1962), Gloyna and Malina (1964), Goering and Parker (1971), Shaw and Fredine (1971), and Keefe (1972).

The marshes as observed in this study can be separated into two basic types; the "solid ground" saltgrass marsh and the "boggy" delta marshes that are dominated by alligator-weed. The major importance of the solid ground marsh is its use largely as cattle pasture and as a habitat for nutria, waterfowl, shore birds, and other wildlife. Birds, mammals, and invertebrates consume a significant portion of the marsh vegetation. In return, animal feces and the decomposition of plant and animal matter contribute nutrients to the bay. The flow of fresh water through the marshes and the salinity gradient, that is consequently maintained, serves to control the plant species composition and distribution. Reduced river flows and subsequent higher salinities could cause species compositional changes and change much of the fresh to brackish water marshes into higher salinity salt marshes. The effect of this change on total productivity is difficult to assess. According to Phleger (1971), plants subject to tidal inundation grow best in fresh water. In contrast, the salt grasses are generally more productive than the purely fresh water species (Wass and Wright, 1969). If reduced river flows eliminated "flushing" of the marshes, then much organic detritus and great amounts of nutrients would be lost to the energy budget of the bay. Also, without the flushing of flood waters, deposition in the marshes would increase and perhaps cause a loss of habitat for the larval organisms that use the area as a nursery. Presently, animal wastes and dead plant matter accumulate in the marshes, mostly during the winter. With high water and high river discharges in the spring, these massive amounts of detritus and nutrients are swept into the bay, providing an immeasurable contribution to the nutrient budget of the bay. A massive discoloration of the water of the entire southwestern third of Trinity Bay was dismissed [illegible] inhabitants of the area as the "normal" spring flushing of the marshes. The water quality parameters measured were not of the type which could be used to define the cause of the discoloration of the water.

Figure 39 illustrates our interpretation of the distribution of the basic vegetation communities of the study area. This figure differs from the delineation of the various Trinity Bay marsh types as given by Fisher, *et al.* (1972) in three major ways: 1) Fisher, *et al.* (1972) show salt water marshes along the bay, extending northward along Cross Bayou, and in an area immediately adjacent to Anahuac. Our observations cannot support the existence of such extensive areas of salt water marsh. The entire delta area is dominated by fresh water plant species with the distributary levees supporting larger species; such as, goldenrod and reeds. Although the Cross Bayou area is influenced by bay waters, we observed large stands of reeds indicating a greater fresh water influence from Old River Lake than from the salt water influence of the bay. 2) Our observations indicate that the fresh water influence along Long Island Bayou is great enough to support fresh water species, because the area was dominated by alligator-weed throughout the entire study period. On the other hand, saltgrasses dominated the area during the low flow conditions found in August 1972. This is direct and dramatic evidence that the seasonal salinity regime controls species distribution in the marshes. 3) There is only one discernible difference between the marshes near the bay and the marshes occurring farther north near Old River Lake; *i.e.*, the replacement of *Spartina alterniflora* (a high salinity tolerant species) near the bay edge by *Spartina patens* (a species less tolerant of saline water) further from the bay shore.

Figure 39. Map of Trinity Bay marsh area with areal coverage of generalized vegetation communities.

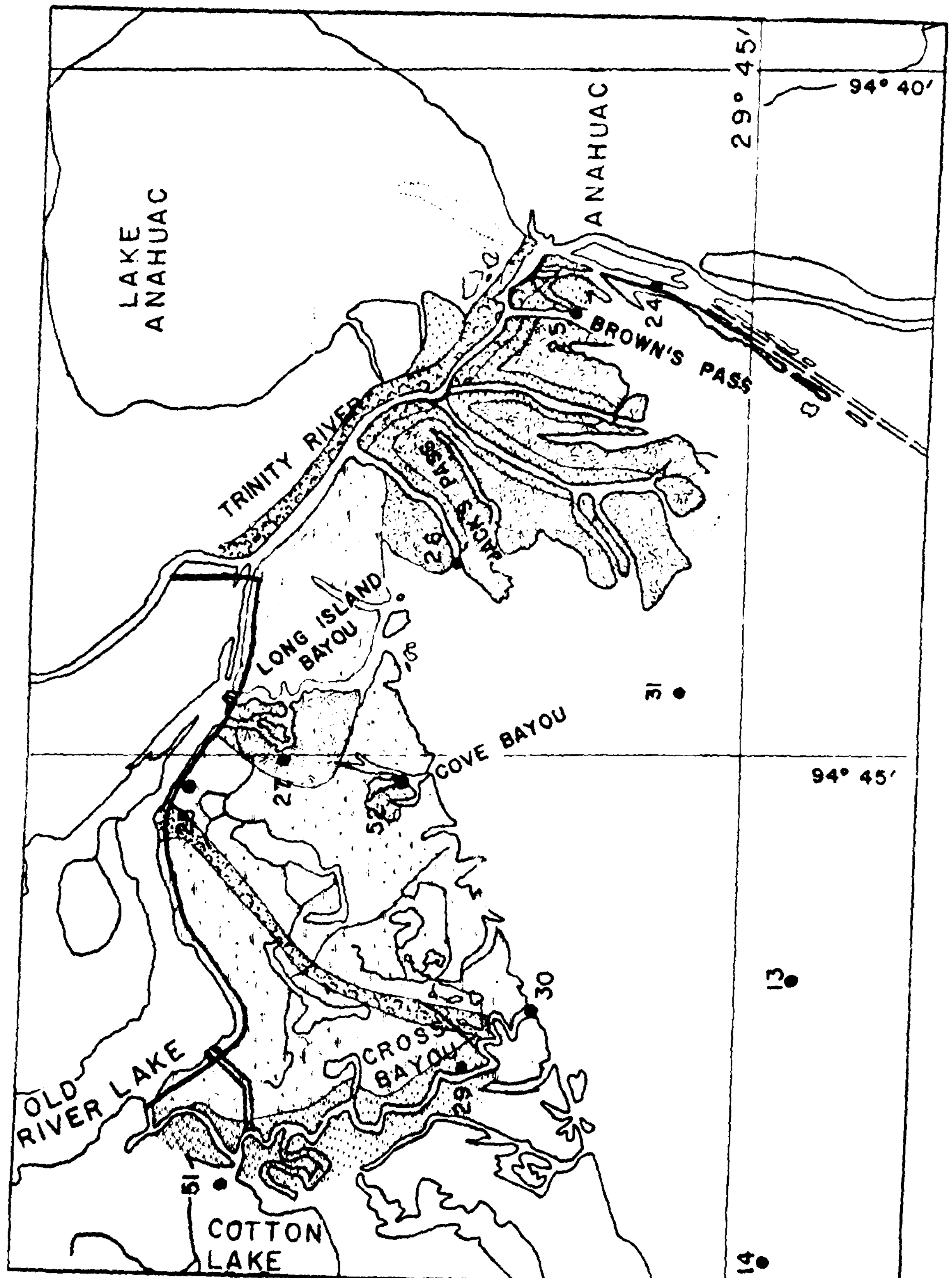
LEGEND

- Fresh to brackish to salt marsh. Species composition varies with heavy fresh water influence in the north and salt water influence near the bay. The predominant species are: *Spartina* spp., *Distichlis spicata spicata*.

- Community along raised edges of passes. The predominant species are: *Solidago sempervirens*, *Scirpus* sp., *Phragmites communis*.

- Woody vegetation on elevations of 1 to 2 meters. Trees may or may not be present. The predominant species are: *Quercus* spp., *Prunus* sp., *Taxodium distichum*, *Nyssa* sp., and *Tamarix gallica*.

- Areas dominated by succulent alligator-weed, *Alternanthera philoxeroides*.


LAKE ANAHUAC
ANAHUAC
29° 45′
94° 40′
94° 45′
BROWN'S PASS
24
25
TRINITY RIVER
JACK'S PASS
26
LONG ISLAND BAYOU
31
COVE BAYOU
27
28
52
30
13
CROSS BAYOU
29
OLD RIVER LAKE
51
COTTON LAKE
14

Much of the soil surface of the marshes, except for the delta interdistributary marshes, is above water all year except for during high spring water levels. This fact contributes to the predominance of fresh water over low-salinity marsh species. Elevations of one to two meters occur adjacent to Cove Bayou and then along The Ridge which extends from near the mouth of Cross Bayou, northeast to the northern most point of land extending into Old River Lake. These areas of higher elevation support much woody vegetation and some sizable trees. More importantly, The Ridge serves to separate the marsh into two areas. The area above The Ridge is characterized by fresh water nearly all the time, while the area below The Ridge is subject to inundation by bay waters during storm tides or wind-driven high water levels. The degree of influence of fresh or saline water controlling the species composition in the marshes is thus modified by the physical barrier of The Ridge.

Benthic Invertebrates and Diversity

The bottom dwelling infaunal invertebrates, as a group of organisms, are extremely vulnerable to stress from overlying waters because they are unable to leave if conditions become intolerable. The infaunal benthos may have to adapt or die. Because of this, they are excellent indicators of estuarine "health". For example, normal populations of benthic invertebrates in Cedar Bayou were eliminated under severe brine-induced stress (Culpepper, *et al.*, 1969).

The benthos of several Texas bays are reported to occur in numbers from 800 to 80,000/m^2 (Parker and Blanton, 1970). Mackin (1971) reported populations of benthic invertebrates in Trinity Bay ranging between 45 and

30,645/m^2. The numbers observed in this study ranged from 50 to 126,100/m^2. The maximum populations in the study by Mackin (1971) occurred in July when salinities and temperatures were near 17 $^{o}/oo$ and 26°C respectively. The highest faunal counts observed during this investigation occurred in August when bottom salinities averaged 14.5 $^{o}/oo$ and temperatures averaged 26.5°C, which are in close agreement with Mackin's observations. Further comparisons showed that, in general, the correlations between salinity and benthos were quite similar in both studies. Lowest numbers of invertebrates were observed during both studies in the winter months, coincidental with low salinities. In 1971, spring and summer salinities were high and benthic animals averaged near 15,000/m^2 (Mackin, 1971). In the spring of 1973, the salinities were very low; consequently, benthos averaged only 7,000/m^2, or half the 1971 numbers. Although the benthos did not correlate well with salinity throughout the entire study period, they do appear to be influenced by major salinity changes, as can be seen on Figure 35.

Sanders, Mangelsdorf, and Hampson (1965) discussed the direct effects that salinity had on faunal distribution in an east coast estuary. They found that epifaunal forms were poorly represented in the communities because of large tidal-induced salinity fluctuations, while the number of infaunal forms was relatively stable and high. While Sanders, *et al.* (1965) were concerned with tidal fluctuations in salinity, the principle they defined also applies to longer term salinity fluctuations. The principle brought out in that paper was that the interstitial waters of the sediments are little affected by short term salinity changes in the overlying waters. On the other hand, long term salinity changes in the overlying waters will change the interstitial salinities and thus affect the benthos. The relationship between benthos, salinity, and sediments can be seen on Figure 36. Large numbers of invertebrates were found in samples that were characterized by massive amounts of detritus, an observation also noted by Williams (1972). The large amounts of plant matter may furnish a carbon source for primary benthic production (bacteria) and thus promote high standing crops of benthic invertebrates.

Mackin (1971) observed that the diversity of benthic invertebrates was higher in areas of lower salinity. He felt that increased predation and parasitism by species less tolerant of low salinities were responsible for this high diversity. The diversity index calculated in this study and its relationship to numbers of benthos can be seen on Figures 22 and 35. The average diversity indices for each sampling period were remarkably stable from month to month. No other parameter in the study showed as little fluctuation, as the diversity indices varied only one-tenth of an index point from one trip to the next. As no other parameter was stable throughout the study, diversity does not correlate with any other factor. Stable diversities more likely testify to the fact that over the thousands of years that the Trinity estuary has been inhabited by benthic infauna, the organisms have evolved into extremely tolerant and extremely adaptable forms that can withstand temperature and salinity fluctuations of great magnitude.

Nekton and Epifauna

The numbers of nektonic and epifaunal organisms in Trinity Bay fluctuated widely during the study period. These organisms are quite mobile and can migrate in and out of the estuary whenever conditions become intolerable. An illustration of the nektonic and epifaunal fluctuations can be seen on Figure 35. All of the catch per unit effort data for shrimp, crabs, and the five most abundant species of fish were lumped together in a single graph. The single-line graph may not be representative of the true catches per unit effort, but Table 6 and Figure 23 show that not enough organisms were collected to treat statistically. We believe this to be a function of the large mesh used in the trawl and seine. The largest numbers of fish were caught in December, March, and May. Croakers were present in all sampling periods. Brown shrimp were caught from February to May, although the first instar stages are not reported to enter the bay until June or July (Baldauf, *et al.*, 1970; Moffett, 1965). Blue crabs were caught at all trawl and seine stations. The data are too meager for defining the seasonal distributional patterns for the important fish and shellfish species of Trinity Bay; however, an adequate body of literature exists that can supply such data. Among those references are Reid (1955), Gloyna and Malina (1964), Moffett (1965), Johnson (1967), Trent, *et al.* (1967), Parker, *et al.* (1969), Baldauf, *et al.* (1970), Copeland and Bechtel (1971), Parker (1971), and Strawn, editor, (1972). The significance of this and other studies is that they confirm the contention that the Trinity Bay estuary contains many of the sports and commercial species of fish and shellfish at all times of the year, even during particularly high water conditions in the spring. The excellent paper by Copeland and Bechtel (1971) points out the following seasonal inhabitants of the estuary: menhaden are present from April to November; sand trout are present year round, with a

TABLE 6

KINDS AND NUMBERS OF ORGANISMS TAKEN BY TRAWL AND SEINE, IN TRINITY BAY, 1972-1973

Species	Bay				Marsh			
	Dec.	Feb.	Mar.	May	Dec.	Feb.	Mar.	May
PHYLUM: Coelenterata								
CLASS: Scyphozoa								
Jellyfish	1	26						
PHYLUM: Ctenophora								
Comb jellies		2						
PHYLUM: Anthropoda								
CLASS: Crustacea								
ORDER: Decapoda								
Family: Penaeidae								
Penaeus aztecus			3			1	1	1
Brown shrimp								
Family: Portunidae								
Callinectes sapidus	1	29	11	12		2	37	3
Blue crab								
PHYLUM: Vertebrata								
CLASS: Osteichthyes								
ORDER: Clupeiformes								
Family: Clupeidae								
Brevoortia patronus	120	2		1			1	146
Gulf menhaden								
Dorosoma petenense	5	1				37		
Threadfin shad								
D. cepedianum								10
Gizzard shad								
Family: Engraulidae								
Anchoa mitchilli		8					14	
Bay anchovy								
ORDER: Siluriformes								
Family: Ictaluridae								
Ictalurus punctatus					2			
Channel catfish								

TABLE 6 (continued)

Species	Bay				Marsh			
	Dec.	Feb.	Mar.	May	Dec.	Feb.	Mar.	May
Family: Ariidae								
Arius felis			1					
Sea catfish								
ORDER: Atheriniformes								
Family: Cyprinodontidae								
Fundulus similus						1	67	
Longnose killifish								
F. grandis						2	16	
Gulf killifish								
ORDER: Gasterosteiformes								
Family: Syngnathidae								
Syngnathus scovelli						1		
Gulf pipefish								
ORDER: Perciformes								
Family: Sciaenidae								
Leiostomus xanthurus				4				2
Spot								
Micropogon undulatus	10	25	588	89		5	35	3
Atlantic croaker								
Family: Mugilidae								
Mugil cephalus	1			1				2
Striped mullet								

peak season of May to November; crabs are present year round, with spring and fall peaks of abundance; white shrimp are present year round, but only in great numbers from July to December; pink shrimp are present year round, but abundant only in summer and fall; brown shrimp are present from March to December; and oysters are, of course, always present but are harvested only from November to April.

Inspection of the seasonal population structure of the estuary makes it obvious that if the river flow is managed for the benefit of one species, it would probably negate the survival of other species. Copeland and Bechtel (1971) defined optimal salinity and temperature ranges for the above mentioned commercial species and in several cases the optimum ranges for the different species are in conflict. Crabs and brown shrimp are relatively tolerant of the total range of natural salinities. High salinities would favor pink shrimp survival, but would permit the increase of oyster predators and parasites, and might be limiting to menhaden and sand trout in the fall, and white shrimp at all times. Low salinities would favor menhaden, sand trout, crabs, white shrimp, and oysters, but could limit pink and brown shrimp production. By managing the bay salinities to enhance the crustaceans and mollusk populations (through salinity reduction), the croaker and spot fisheries could possibly be increased--as these species feed primarily on crustaceans and mollusks (Reid, 1955). Low salinities also would favor the increase of the menhaden population, which serves as the primary food of speckled sea trout--as found in 89 percent of all trout stomachs observed by Reid (1955). Menhaden are also important as food for croaker, catfish, ladyfish, and lizardfish (Reid, 1955). Reid states that the shad and anchovy populations are primarily dependent on plankton for food, which means that the higher salinities necessary for increased plankton populations would probably enhance the shad and anchovy fisheries. Shrimp serve as prey for more species than any single group of organisms; therefore, regulating salinity levels for shrimp would increase both the shrimp fishery and other fish populations dependent on shrimp, as well. Regulating salinities for shrimp would mean keeping salinities below 25 $^{o}/oo$ for white shrimp, greater than 20 $^{o}/oo$ for pink shrimp, and, when temperatures are low, salinities would have to be kept high for brown shrimp. However, brown shrimp are very tolerant to most salinity extremes under "normal" conditions. It should be emphasized again that these guidelines were established by Copeland and Bechtel (1971). Baldauf, *et al.* (1970) cited that an inverse correlation exists between river discharge and abundance of crustaceans. Any management of river flow established to attain desired salinities must be carefully weighed. Fishery statistics from the years 1958 to 1968 showed that during those years when average winter salinities exceeded summer salinities, the annual seafood landings were reduced (Parker and Blanton, 1970). Winter salinities were higher than summer salinities because of high water flows in the spring and summer. The evidence provided by the above authors indicates that high salinities have not influenced commercial landings as much as have low salinities which occurred during normally high salinity periods.

The importance of management precaution is seen in the fishery statistics derived from the Galveston Bay complex. The entire bay complex is responsible for five percent of the Texas fish landings, 13 percent of the shrimp landings, 70 percent of the crab landings, and 85 percent of the oyster harvest (Farley, 1972). Any water management decision that could yield a negative impact on any of the sports or commercial fisheries would have a major economic effect on the Galveston Bay region. Computer modeling will become an invaluable tool in formulating any future management decisions as all the necessary variables, which need to be considered, can only be correlated with a computer program.

Sediment Composition

Changes in the sediment composition during the study period as they relate to the bacterial and benthic populations are shown on Figures 28 and 36. The literature on the relationship between benthos and sediments is voluminous. Generally, coarser sediments are more productive than fine sediments. Counts of benthic animals from Aransas Bay numbered 9,000/m^2 on clay sediments, 20,000/m^2 on sandy sediments, and 80,000/m^2 on sand flats with emergent vegetation (Parker and Blanton, 1970). From these data it is evident that sediment type plays an important part in determining standing crops of benthos. It is significant that the presence of vegetation coincides with the highest counts of benthic invertebrates. Juvenile shrimp are dependent upon grass beds for protection along with abundant detritus on soft bottoms (Baldauf, *et al.*, 1970). Organic matter content is an important factor in determining productivity of sediments for benthos. Organic matter can be broken down easier in coarse sediments and can accumulate in greater amounts within the relatively large spaces between sand grains. Fine, well-sorted sediments tend to adsorb organic matter and also to pack together tightly, thus removing the organic matter from the food chain (Volkmann and Oppenheimer, 1962). In the case of San Antonio Bay, Davis (1971) believed that the sediments are the singularly most important contributing source of nitrogen, phosphorus, and carbon for the nutrient budget of the bay. However, the data from this study do not show any direct correlation between sediment composition and benthos, although there is a direct correlation between sediment type and bacterial numbers in the sediments. With a decrease in clay and a permanent increase of sand, the numbers of sedimentary bacteria increased and remained high for the duration of the study. This same phenomenon was observed in the Copano Bay region after Hurricane Beulah (Berry, 1969). Since we believe that bacteria form a major component of the primary production in Trinity Bay, this correlation is important. High river flows apparently flush out portions of silt and clay from the bay thus leaving coarser sediments on the bay floor. The bacteria apparently responded with an increase in numbers. If river discharges were reduced on a long term basis, it is possible that sand deposition in the bay might increase. Even though the annual sediment load of the river would be decreased, the contributions of sand from Double Bayou, Lone Oak Bayou, and shore erosion would continue. Although the many upstream reservoirs already trap the bulk of sediments in the Trinity River, Lankford, *et al.* (1969) indicates that about 3,000 acre feet of sediment could accumulate in the bay each year, and that with natural processes alone, the Galveston estuary would disappear in 600 to 900 years.

Hydrology and Circulation

The previous discussion needs to be set into the perspective of the hydrologic conditions in Trinity Bay. A map of the general circulation and net flow of water within Trinity Bay is given on Figure 40. The arrows in the figure denote direction but not absolute velocity. This diagram is a modification from Bernard Johnson Engineers, Inc. (1971), Tracor (1970), and Espey, *et al.* (1971). Our modifications were made after observing the operation of the scale model of Trinity Bay at the U.S. Corps of Engineers Waterways Experiment Station and observing series of NASA Gemini photographs. Wind as a factor in causing tidal fluctuations is important and that it influences circulation cannot be ignored, but Masch and Espey (1967) state that wind generated currents have little effect on the overall circulation in Galveston Bay. The two wind rosettes on Figure 41 show that there should not be a theoretical net effect of wind on Trinity Bay circulation. Tidal levels, however, are more frequently raised or lowered as a result of prolonged winds than by astronomical forces. High wind tides have a greater effect on erosional processes than normal tidal circulation. Tidal currents are often more important in Trinity Bay circulation than wind or river discharge. Lankford, *et al.* (1969) state that tidal currents daily transfer almost three times the volume of the runoff of the Trinity and San Jacinto Rivers combined into and out of Galveston Bay. The net effect of tidal transport within the bay is to quickly diminish the effect of river currents within a few miles of the mouth of Trinity Bay. The Houston Ship Channel and San Jacinto River waters also enter Trinity Bay, but again the net effect is diminished before these waters reach the center of Trinity Bay.

The chemical effects of both Gulf waters and Houston Ship Channel waters on Trinity Bay ecosystems are often very obvious (Parker, *et al.*, 1972). In addition, those authors demonstrated that the distribution patterns of certain of the environmental parameters closely reflected the circulation patterns. This supports the statement made earlier that many of the parameters observed are affected more by local hydrological and meteorological conditions in the bay than by the flow of the river.

A point made earlier should be reiterated. Lankford, *et al.* (1969) stated that 19.5 percent of the Trinity River discharge comes from runoff of the last 45 miles of the drainage basin, which is that portion of the basin below Romayor. Using discharge figures for the Trinity River at Romayor for the years 1951-1964, as reported in More (1965), the average discharge for those years was 3.75 million acre feet. Using Lankford's approximation of the contribution of the lower drainage basin, Trinity Bay--under conditions prior to 1965--was assured of an average of 731,250 acre feet each year. In the most severe drought year (1956), the lower drainage basin below Romayor should have contributed 175,500 acre feet to Trinity Bay. We believe the recommendation, made by the National Technical Advisory Committee (1968), that the isohaline pattern of an estuary not be altered by more than ±10 percent of the normal variation, should be applied to the flow of the Trinity River, which is the governing factor in maintaining the salinity gradient in Trinity Bay. Using our interpretation of the National Technical Advisory Committee's recommendation would mean that the lowest flow of the Trinity River, approximately 900,000 acre feet at Romayor in the 1956 water year, should never be reduced by

Figure 40. Generalized net flow and circulation patterns, Trinity Bay, Texas (Bernard Johnson Engineers, 1971; Tracor, 1970; and Espey, *et al.*, 1971).

LEGEND

⟶ Trinity River Flow

— · → Houston Ship Channel Water

- - - → Gulf Tidal Influx

Figure 40. Generalized net flow and circulation patterns, Trinity Bay, Texas (Bernard Johnson Engineers, 1971; Tracor, 1970; and Espey, *et al.*, 1971).

LEGEND

⟶ Trinity River Flow

–·→ Houston Ship Channel Water

---→ Gulf Tidal Influx

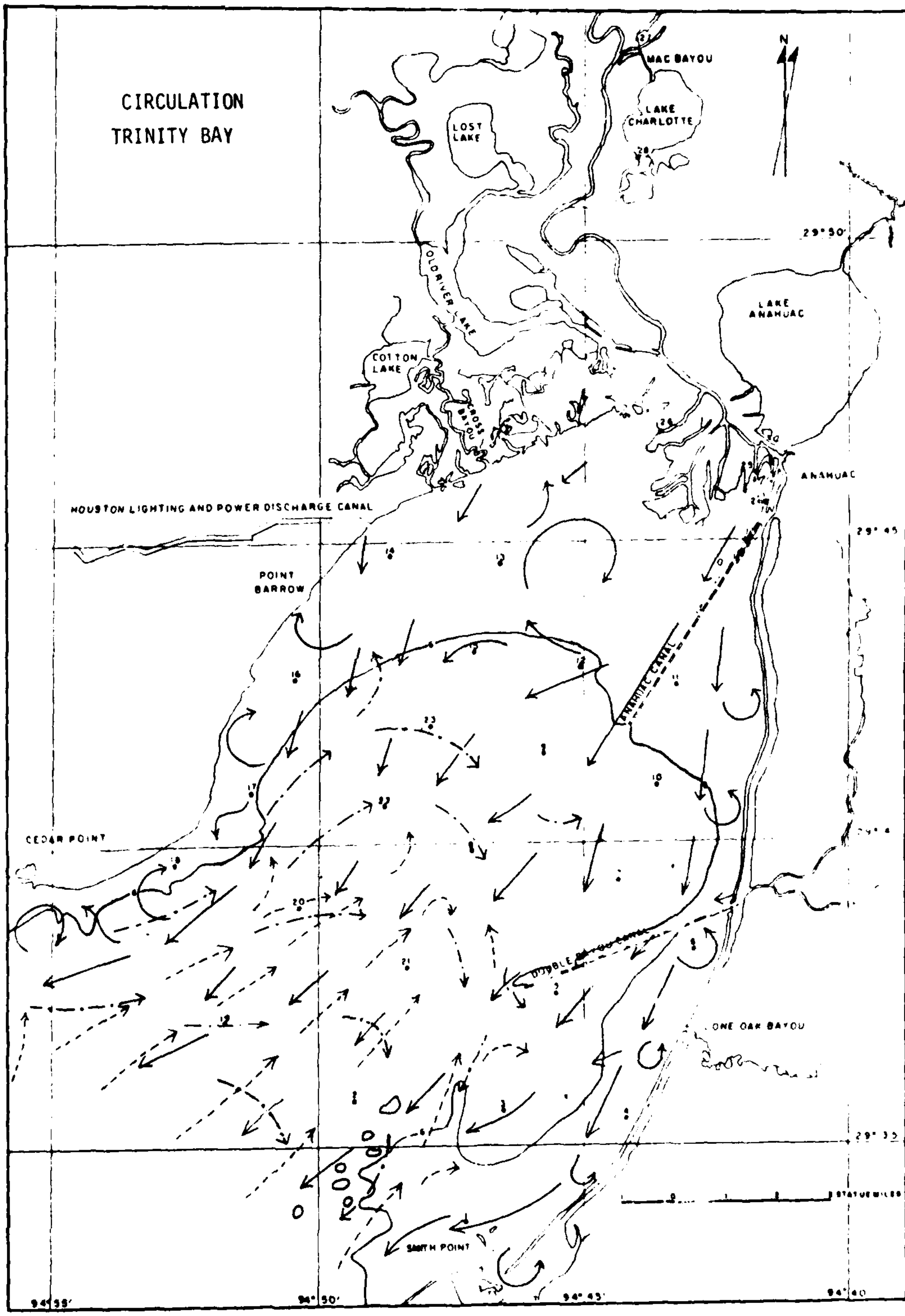
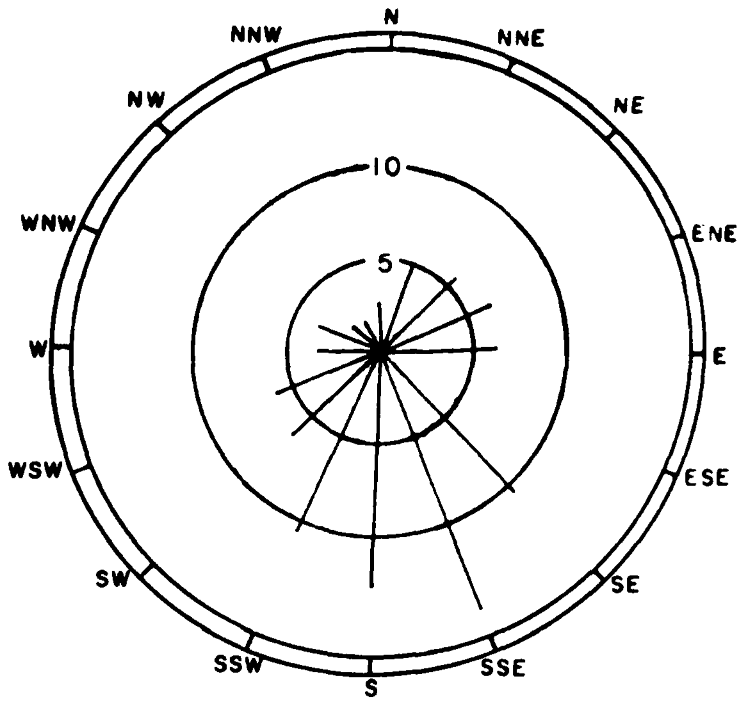

CIRCULATION
TRINITY BAY
MAC BAYOU
LAKE CHARLOTTE
LOST LAKE
N
29° 50'
OLD RIVER LAKE
LAKE ANAHUAC
COTTON LAKE
CROSS BAYOU
ANAHUAC
HOUSTON LIGHTING AND POWER DISCHARGE CANAL
29° 45
POINT BARROW
ANAHUAC CANAL
CEDAR POINT
DOUBLE BAYOU CANAL
ONE OAK BAYOU
29° 35
STATUTE MILES
SMITH POINT
94° 55'
94° 50'
94° 45'
94° 40

Figure 41. Wind rosettes - Galveston Bay, Texas.

A. % frequency of direction, August 1970 (Tracor, 1970)

B. % frequency of direction x average speed, 1951-1960 (NOAA, 1970)

A.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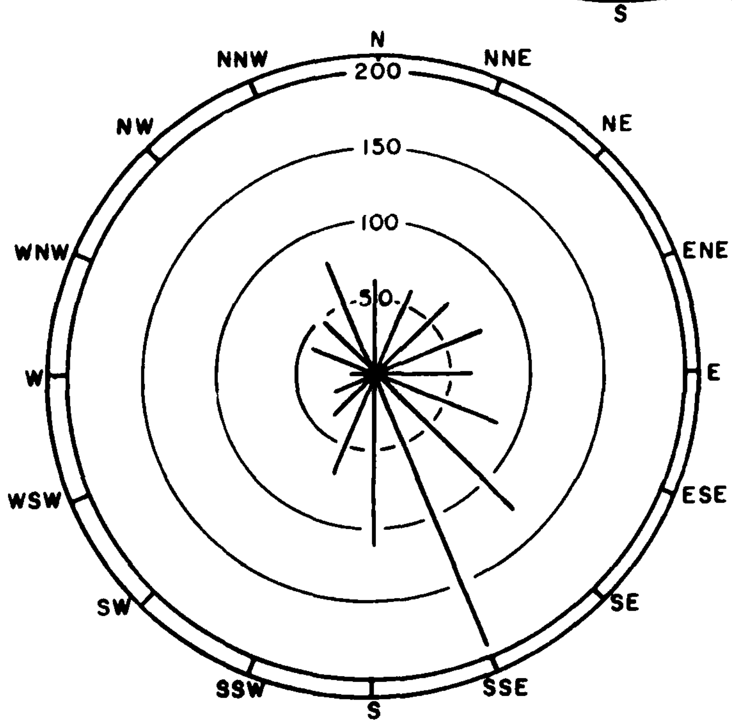
B.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SSW
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WSW
W
WNW
NW
NNW
200
150
100
50

more than 10 percent. This would guarantee that the bay would be flushed 1.2 times in the course of the year. The volume of the bay is reported as 654,200 acre feet and the low flow of 1956 was 900,000 acre feet, so that a 10 percent reduction of 900,000 equals 810,000 acre feet, or 1.2 times the volume of Trinity Bay.

SUMMARY AND CONCLUSIONS

The consensus of opinion of several investigations into the Trinity Bay ecosystem is that the bay is dependent upon the river for nutrients and for maintenance of the salinity gradient. Odum, *et al.* (1963), Copeland and Fruh (1970), Espey, *et al.* (1971), and Copeland, *et al.* (1972) cite the bay metabolism as being heterotrophic and having an excess of respiration over photosynthesis. This suggests that nutrients are being regenerated faster than they are being used, allowing a high rate of photosynthesis. However, photosynthesis never exceeds respiration because of immediate further biological utilization, which is secondary productivity (Copeland and Fruh, 1970). This metabolic regime is maintained by high loadings of organic matter (Espey, *et al.*, 1971). We are in agreement with the above authors, except that we do not believe the bay is as dependent upon river-borne nutrients as previously thought. We believe part of the secondary production and thus part of the excess respiration is derived from primary consumers which utilize the large benthic bacterial biomass as a source of energy. On the other hand, the bay will always be dependent on river flow for the maintenance of the salinity gradient.

Conclusions

- River flow has little or no effect on bay temperatures.
- River flow has little or no effect on dissolved oxygen in the bay.
- The salinity gradient of the bay is a direct result of river flow.
- River flow affects pH slightly by contributing certain of the chemical factors that influence pH, and by the process of dilution with fresh water.
- Hydrogen ion concentration, dissolved oxygen, and phosphorus are directly related to one another in the bio-energetics of the bay ecosystem.
- Eh is a function of oxygenation and water movement and thus may be influenced by river flow induced circulation. Reduced circulation from low river flows could possibly decrease Eh values.
- River flow contributes much of the suspended matter that essentially influences turbidity. High river flows contribute much more suspended matter proportionally, than do low river flows. However, even if high river flows were reduced, thus reducing the suspended sediment load, turbidities in the bay would not be significantly reduced, since winds and wave action are the primary causes of high turbidities in the bay.
- The trace metal ions--mercury, lead, iron, copper, and zinc--are little affected by the influx of the river.
- Magnesium is indirectly affected by river flow in that magnesium is directly related to the intrusion of high magnesium content salt water.

Calcium is little affected by river flow, so that the Mg/Ca ratio is mostly the result of the salinity gradient maintained by the river.

- Nitrates and nitrites enter the bay largely in the river discharge. Their concentrations do not correlate with river flow.

- Orthophosphates may possibly show enrichment with depth. Most of the phosphate enters the bay from the river, but concentrations do not correlate with flow.

- Sulfate ions appear to be inversely correlated with river flow, and reflect more the intrusion of Gulf waters.

- Total organic carbon concentrations in the bay are not directly related to river discharge rates, although concentrations in the bay are similar to those occurring in the lower reaches of the river. The percentage of total carbon which is organic is directly related to river flow as the river and marshes are a major source of organic carbon. The Houston Ship Channel also may contribute organic carbon to the bay. Large amounts of organic matter are flushed from the marshes by high water flows.

- Of the three most important factors controlling life processes, salinity, dissolved oxygen, and temperature, only salinity is related to river flow.

- High coliform counts in the bay were attributed to influx of animal wastes from the marshes and sewage discharges from Anahuac and Double Bayou.

- Bacterial counts in the sediments were three orders of magnitude higher than those from the water column. Sediment bacteria numbered near $1x10^{10}$. Populations this large possess a biomass large enough to affect the entire ecosystem.

- High populations and biomass of bacteria, correlated with high total organic carbon plus large amounts of organic matter flushed into the bay, support the thesis that bacteria may form the base of primary production in Trinity Bay.

- Phytoplankton populations are very low in Trinity Bay. Plankton populations and the amounts of chlorophyll-a in surface waters were not related. Chlorophyll-a did not correlate with either river flow or temperature, but did correlate well with phosphate concentrations. Plankton populations varied in the same direction as total organic carbon, but displayed no real correlation with nitrates and nitrites.

- The standing crop of marsh vegetation was not related to river flow except when flooding prevented initial growth. Light and temperature exert greater control of the marsh vegetation than does river flow.

- The marshes are basically of two types. The delta marshes are very boggy and are dominated by fresh water species (especially alligator-weed), and the levees along the major passes support many larger fresh water species. The marshes west of the delta are characterized by fresh to medium salinity species; such as, saltgrass and cordgrasses. The species composition of the marshes is controlled by the salinity regime which in turn is controlled by river flow; wind tides; and the physical barrier of The Ridge, which runs across the western marshes.

- Benthic invertebrate populations did not vary with the river flow. Large numbers of benthic invertebrates always occurred in samples with large amounts of detritus present.

- The diversity index of the benthic communities was very stable throughout the entire study, in spite of fluctuations of all environmental parameters.

- Epifaunal and nektonic organisms fluctuated widely in numbers during the investigation. Statistically significant numbers were not collected, possibly because of inappropriate gear. Croakers, brown shrimp, and crabs were regularly taken throughout the study.

- The Trinity Bay estuary contains some of the sports or commercially important species of fish and shellfish at all times of the year. Management of river flow might result in increased populations of some species but, at the same time, depress populations of others.

- Sediments showed a decrease in percentage of clay and an increase in percentage of sand, while the silt fraction remained stable. These sedimentary composition changes were observed to be directly proportional to river flow.

- Bacterial populations within the sediments were directly related to changes in sediment composition. There was little or no correlation between sediment changes and benthic infauna.

- Circulation in the bay is derived from Trinity River inflow, tidal intrusion from Bolivar Roads, and waters derived from the Houston Ship

Channel and the San Jacinto River.

- The Trinity Bay ecosystem is dependent on the river flow for both nutrients and for maintaining the salinity gradient. Extremely localized geochemical and water quality conditions are more important than the river flow in maintaining normal productivity.

- Trinity Bay is heterotrophic and has high organic matter loadings. Primary productivity is a combination of planktonic and bacterial oxidation, which is responsible for high total biologic production.

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APPENDIX A

LOCATIONS AND DEPTHS OF C.E.M. STATIONS, TRINITY BAY REGION

Station	Latitude (north)	Longitude (west)	Mean Depth (meter)	Visual Reference
1	29°33'40"	94°47'10"	1.4	200 meters north of Vingt-un-Island
2	29°35'50"	94°49'35"	3.1	
3	29°35'35"	94°46'45"	2.6	
4	29°35'25"	94°44'15"	1.6	200 meters off Hodges Island
5	29°37'35"	94°45'35"	2.5	100 meters south of Double Bayou Marker #2
6	29°38'20"	94°43'00"	2.1	100 meters south of Double Bayou Marker #12
7	29°39'25"	94°44'25"	2.8	
8	29°39'50"	94°47'10"	2.2	
9	29°41'30"	94°45'35"	3.0	1 kilometer west-southwest of sea buoy end of Anahuac Channel
10	29°41'00"	94°43'45"	2.3	50 meters north of Wellhead #42
11	29°42'40"	94°43'25"	1.2	West bank Anahuac Channel Marker #9
12	29°43'05"	94°45'05"	2.6	Point of isosceles triangle west of Anahuac Channel canal #1 and sea buoy
13	29°44'45"	94°46'30"	2.4	50 meters north of Wellhead #85
14	29°44'55"	94°48'35"	1.8	400 meters off mouth of Houston Lighting and Power Canal
15	29°43'20"	94°47'05"	2.7	
16	29°42'45"	94°50'20"	2.4	South of sunken barge, off large open house lot north of dirt banks
17	29°40'55"	94°51'10"	2.7	
18	29°29'30"	94°52'50"	1.8	500 meters off horseshoe driveway at Crawley's Camp

APPENDIX A (continued)

Station	Latitude (north)	Longitude (west)	Mean Depth (meter)	Visual Reference
19	29°37'05"	94°51'50"	3.6	700 meters northwest of flasher on oil platform
20	29°38'40"	94°50'20"	3.2	
21	29°38'00"	94°48'20"	3.6	
22	29°40'40"	94°48'50"	3.0	
23	29°42'00"	94°48'00"	3.2	
24	29°45'25"	94°41'40"	1.0	Anahuac Channel Marker #27--right bank
25	29°46'05"	94°41'50"	0.6	Left bank of Brown's Pass at mouth
26	29°46'50"	94°43'30"	0.6	Right bank, 100 meters from mouth of Jack's Pass
27	29°47'50"	94°45'00"	0.5	150 meters west of largest east-west channel
28	29°48'15"	94°45'10"	0.6	C.E.M. marker
29	29°46'40"	94°47'15"	1.3	Left bank, C.E.M. marker
30	29°46'30"	94°46'45"	2.7	C.E.M. marker, right bank at mouth of Cross Bayou
31	29°45'10"	94°44'20"	1.8	300 meters north of center of overhead powerline
32	29°43'42"	94°42'52"	0.7	Anahuac Channel Marker #11
33	29°41'48"	94°42'10"	2.0	
34	29°42'02"	94°44'13"	2.9	500 meters southwest of sea buoy past end of Anahuac Channel
35	29°42'33"	94°46'08"	2.6	
36	29°43'34"	94°48'18"	2.5	700 meters east of Point Barrow Channel
37	29°41'47"	94°49'22"	2.8	
38	29°41'00"	94°47'00"	2.8	

APPENDIX A (continued)

Station	Latitude (north)	Longitude (west)	Mean Depth (meter)	Visual Reference
39	29°40'23"	94°45'03"	2.7	50 meters east of Separator "CCI"
40	29°40'00"	94°42'44"	2.0	
41	29°38'00"	94°44'12"	2.0	
42	29°38'52"	94°45'40"	3.0	
43	29°39'26"	94°48'24"	3.6	
44	29°40'05"	94°50'10"	3.1	Near spar marker without lights
45	29°38'24"	94°54'00"	2.2	300 meters off long dock and boat ramp, adjacent houses are red and green
46	29°38'27"	94°51'42"	1.7	200 meters south of iron pole marker
47	29°37'18"	94°49'47"	3.5	
48	29°36'43"	94°47'17"	2.5	
49	29°34'30"	94°45'32"	3.3	
50	29°34'44"	94°48'17"	3.0	
51	29°48'10"	94°47'50"	0.9	Triangular marker in channel across lake
52	29°47'10"	94°45'10"	0.8	West bank of middle channel just north of channel intersections

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